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TESTS OF POLYHYDRIC CHEMICALS FOR FOG DISPERSAL

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A research study related to the FOGGY CLOUD IV Program (of U. S. Naval Weapons Center, China Lake, California) conducted at Arcata, California.

16. Abstract

Cooperative fog dispersal trials were conducted with the FOGGY CLOUD IV Project team at Arcata/Eureka Airport and in Redwood Valley, California. These trials demonstrated that both the rotating screen impactor and the disc particulator can be used to generate finely divided particulate (50 micron diameter median range) of the high viscosity chemicals used for fog dispersal. Glycerine, diethylene glycol, and tetraethylene glycol were successfully generated into a fine mist using these devices. Three runs were made treating fog with glycerine. Visibility improvement was observed, but not measured, in each run.

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PREFACE

The work reported in this document is directly related to Project FOGGY CLOUD IV, conducted at Arcata, California during the latter part of 1971. Project FOGGY CLOUD IV is number four in a series of fog dispersal programs managed by the U. S. Naval Weapons Center (N.W.C.). Project FOGGY CLOUD IV included personnel from:

1. U. S. Naval Weapons Center, China Lake, California.
2. U. S. Army Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico.
3. U. S. Army Meteorological Team, Fort Huachuca, Arizona.
4. U. S. Bureau of Standards, Arcata/Eureka Airport, California.
5. Federal Aviation Administration Flight Service Station, Arcata/Eureka Airport, California.
6. Atmospheric Water Resources Research Group, Fresno State College, Fresno, California.
7. McDonnell Enterprises, Inc.

The effort and the equipment provided by the above organizations to assist in this work are acknowledged with sincere appreciation.

* * * * *

Micronair (Aerial) Limited, Bembridge Fort, Sandown, Isle of Wight, England, have generously given permission to reproduce the drawings of their rotating screen impactor in this report. A copy of their letter of permission is on file at the Department of Transportation, F. A. A. Headquarters, 800 Independence Ave., S. W., Washington, D. C. 20591.

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Key: B-W = black and white print

CP = color print

P = Polaroid black and white print
(Polaroid is a registered trademark of Polaroid Corporation.)

SUMMARY

Research effort on fog dispersal has been active for several years at Dow Chemical U. S. A., Texas Division, Freeport, Texas. This report covers both the present contract effort and those elements at the Texas Division that directly relate to the development of the experimental equipment used in these field experiments. Two mechanical devices have been developed (or modified) and operated successfully to generate finely divided (50 micron diameter range) particles of the high viscosity fluids used in fog dispersal experiments.

Fifteen runs were conducted in conjunction with Project FOGGY CLOUD IV at Arcata/Eureka Airport and in Redwood Valley, California. Most of the operations conducted were either calibration tests or clear air trials to demonstrate capability. However, three runs were made in fog and in each of these, the equipment and the dispersant chemical (glycerine in these fog dispersal trials) demonstrated excellent performance for fog dispersal (visibility improvement). The scarcity of fog during the calendar period allotted for these tests did not permit using each chemical and each particulator in fog. The lack of fog was unexpected. According to the Project FOGGY CLOUD I report, there has been a high incidence of fog during October in the Arcata/Eureka area.*

PURPOSE

The objective of the experimental work covered by this report was to find and demonstrate an effective method for dispersing fog. Before the issuance of the contract for this work, Dow Chemical U. S. A. laboratory tests were conducted using several different methods of treatment of artificial fog in a fog chamber. As a result of these tests it was found that hydrophilic liquids with very low vapor pressure were quite effective as fog dispersants. When fine droplets of the hydrophilic liquid were distributed into the fog, it would rapidly dissipate. Laboratory work then was concentrated on how best to generate fine droplets of these fluids. Since they are generally rather viscous materials, they were found to be difficult to generate into fine droplets. Two methods were successful in generating an adequate cloud of droplets. These methods are discussed in this report.

Using these low vapor pressure hydrophilic liquids as the fog dispersant, the problem resolved to development of methods whereby these liquids could be generated in the desired drop sizes and quantities to achieve optimum visibility improvement in the fog. The results then must meet economic, ecological, and general safety limitations.

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*Blomerth, E. A., "Project Foggy Cloud I," Naval Weapons Center report NWC TP 4929, August 1970, page 6.

INTRODUCTION

Fog has been a disrupting influence on travel since man's first movements from one place to another. Ships have run aground, horses and wagons have been put into all manner of predicaments, and more recently, automobiles, trucks, and aircraft have been subjected to the exasperation and danger of fog. It has been estimated that fog disruptions in the United States alone cost the airlines at least $75 million per year /1, 2/. There is no accurate way to judge the additional losses suffered by passengers and shippers on these airlines.

Dow Chemical U. S. A. recognized the serious problems presented by warm fog and the potential solutions offered by chemical technology. Since 1962, Dow has conducted in-house research on fog dispersal materials and techniques. During the most recent of these studies, sixty compounds were individually tested in fog dispersal tests. These tests revealed marked differences in the ability of certain agents to alter the dissipation rate of a synthetically generated fog.

Using a highly reproducible method, data taken in a 0.2 cubic meter fog chamber consistently show that certain low vapor pressure hydrophilic liquids significantly alter the dissipation rate of a synthetic fog. The effect that an additive has on the natural dissipation rate of a synthetic fog can be measured and compared to a dispersal agent such as sodium chloride which is known to be effective. Glycerine has been shown to be comparable to sodium chloride as a fog dispersing agent based on fog chamber data.

Of those materials known to be ecologically acceptable and which had been tested in the fog chamber, tetraethylene glycol and triethylene glycol were found to be second and third best perfor ·s after glycerine.

Many other materials tested in the fog chamber were found to cause little or no improvement over the natural dissipation rate. Some even stabilized the fog.

Proprietary field tests were conducted by Dow Chemical U. S. A. during November, 1970 to March, 1971 inclusive. These tests were conducted at the Brazoria County Airport near the Dow Texas Division plant site. The tests were designed to evaluate particulation and delivery capabilities as well as fog dispersal effectiveness. Six of these tests produced noticeable precipitation downwind from the seeding apparatus. In two instances a significant improvement in visibility was observed. All six of these tests

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1. Carter, Thomas B., "Clearing the 'Soup,' Airlines Hurry to Fight Fog," Wall Street Journal, 15 April 1968.

2. O'Lone, Richard G., "Chemical Seeding Disperses Airport Fog," Aviation Week and Space Technology, 29 January 1968.

were successful in demonstrating the fog dispersing ability of the agents under evaluation.

Further small scale field testing at the Dow-Freeport facilities would be expected only to provide additional confidence in the aforementioned results and it was reasoned that a scale-up in the size of the experiment would be the next step. Both the needs and timing coincided with the FOGGY CLOUD IV experiments scheduled for September through October, 1971 at Arcata, California.

Three compounds were selected for field evaluation: (1) glycerine, (2) tetraethylene glycol, and (3) diethylene glycol. The basis for the selection included ecological considerations as well as effectiveness in dispersing fog. The compounds chosen have a long-established history in the chemical industry and are considered to be non-corrosive, biodegradable, and non-toxic (to both animal and plant life).

Diethylene glycol is known to perform well, but with somewhat less efficiency than triethylene glycol. The choice of diethylene glycol as one of the dispersant materials was to provide some contrast to the other chemicals being used in the Project FOGGY CLOUD IV field evaluation.

The contract team for F. A. A. arrived to begin operations on 17 October 1971. The Project FOGGY CLOUD IV operations site was located at the Arcata/Eureka Airport. The airport is seven miles north of Arcata, California. After a week of waiting at this site, the whole operation was moved (25 October) to Redwood Valley, California. Redwood Valley is approximately fifteen statute miles due east of the Arcata/Eureka Airport. The test site is in a grassy meadow between steep and heavily wooded hills. The observations made of Redwood Valley by aircraft had repeatedly reported fog there during early morning flights. The valley was also conducive to the formation of radiation rather than advection fog. Thus the probability of having a good workable fog (0.5 mile or less visibility) was presumed to be excellent there. The field trials conducted in Redwood Valley are discussed later in this report.

DEVELOPMENT OF THE PARTICULATION EQUIPMENT

Many devices have been developed for atomizing or breaking up a liquid into small droplets. All of these require an input of energy for creating the expanded surface area. The selection of an acceptable liquid atomizer for use in fog dispersal experiments at Dow was made on the following basis:

1.) The ability to atomize high viscosity fluids ($\simeq$1000 centipoise).

2.) Close control of both the mean particle diameter and the particle size distribution. See Table 1 for the drop size spectrum.

3.) Atomizing rates commensurate with field test requirements (up to 2.5 gallons per minute).

4.) Portability and the size of the required source of particulation energy (drive motor).

5.) Minimizing the weight of particulation equipment to meet the 900-pound payload allowance for the apparatus carried by the hot-air balloon. The maximum payload for this 60-foot diameter balloon was quoted as 1200 pounds. The hot-air balloon used by Project FOGGY CLOUD IV is described below.

HOT-AIR BALLOON SPECIFICATIONS

Manufactured by Raven Industries, Sioux Falls, South Dakota.
Registration Number N4989E.
Type S-60 (Class is now FAA Type Certificated as S-60A).
Nominal Diameter, 60 feet.
Nominal Volume, 105,000 cubic feet.
Maximum (structural limit) Gross Load, 2,000 pounds.
Gross Lift Formula where T represents the ambient air temperature outside the balloon, degrees Fahrenheit:

$$\text{Gross Lift, pounds} = 2956.25 - (14.0625 \times T^{\circ}F)$$

Maximum Burner Output, 4,000,000 British Thermal Units per Hour.
Maximum Internal Air Temperature Limit, 250°F.
Gondola was a specially built rectangular basket about three feet wide by five feet long, made of 0.75-inch diameter stainless steel tubing.

TABLE 1.

ROTATING SCREEN IMPACT ATOMIZER

Run No.*	Speed, (≈ rpm)	Temp., (°C)	Flow Rate (ml/min.)**	Laboratory Data Using Glycerine — Particle Diameters, Microns ϕ Low	Mean	High	Particles Counted
28	7800	24	3350	[illegible]	44	60	[illegible]
29-A	9000	27	3350	32	55	93	311
29-B	9000	50	3350	29	40	61	311
35-1	9000	25	450	15	37	58	534
35-2	8000	25	450	18	47	77	498
35-3	5600	25	450	29	52	75	585
35-4	4400	38	420	45	66	84	462
36-1	4400	38	1154	40	52	69	387
36-2	5600	25	1154	18	52	89	586
37-3	9300	41	3350	18	40	78	556

*All data recorded in book number 13135, Dow Chemical U. S. A., Texas Division.

**Ml/min. is milliliters per minute glycerine flow.

ϕ Figure 1 explains the particle diameters in Table 1, above. These droplets were collected on 1" x 3" Teflon-coated microscope slides, held about 30 inches from the atomizer for about 15 seconds. The droplets were then counted under a microscope in a calibrated field.

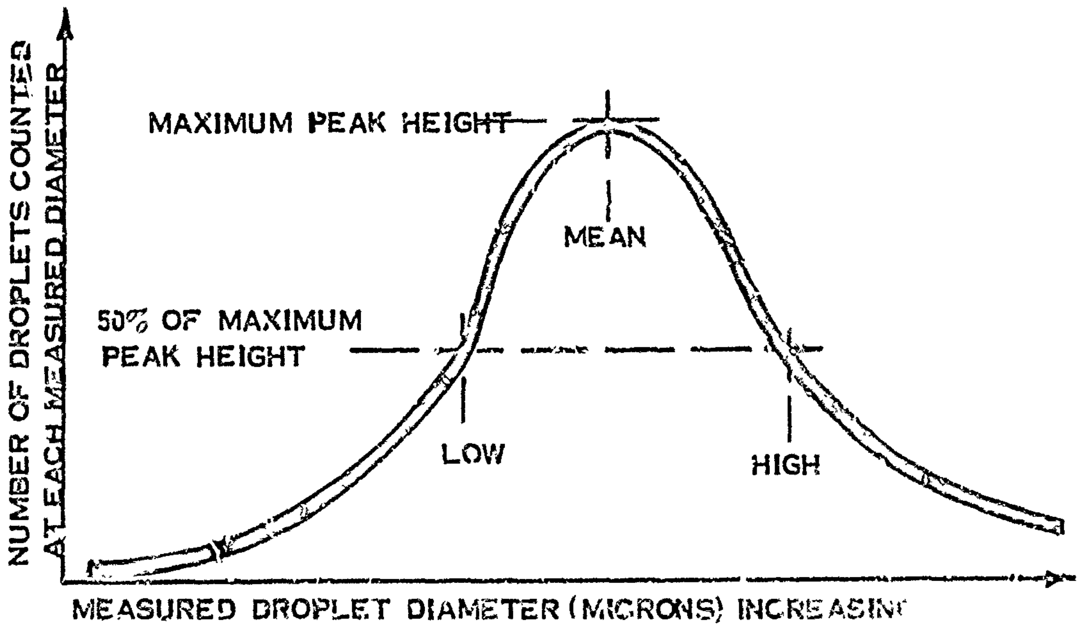

FIGURE I. DISTRIBUTION OF DROPLETS VS DROPLET SIZE (EXPLAINS MEANING OF LOW, MEAN, AND HIGH IN TABLES I AND 3)

Commercially available pressure nozzles of established design were evaluated under optimized conditions using glycerine at room temperature as the test medium ($\simeq$1000 centipoise). The following data were obtained.

TABLE 2.

ATTEMPTS TO SPRAY GLYCERINE WITH VARIOUS SPRAYING DEVICES

	Sonic*	Pneumatic	Hydraulic
Operating Pressure, Lb./In.^{2} Gage			
Atomizing Air	5-150	20-250	**
Liquid Feed	$\simeq$100	$\simeq$ 60	50-1500
Liquid Delivery Rate, ml/min.	400	35	$\simeq$ 50
Average Droplet Size, Microns	$\simeq$ 18	30	**
Percent Droplets > 100 Microns	< 5	$\simeq$ 10	**
Percent Droplets < 10 Microns	10	< 1	**

*Sonic: Sonic Development Corporation Model 188 Sonic Nozzle.
Pneumatic: Spray Systems Type J-2850-70 Pneumatic Atomizer.
Hydraulic: Spray Systems Type N4 Hydraulic Atomizer

**Data on the Spray Systems Type N4 Hydraulic Atomizer are incomplete due to a total lack of break up or particulation at the maximum indicated pressure. In addition to the nozzles listed, other devices employing hydraulic pressure were evaluated with little, if any, success. Notable among these were (a) pin-jet impingement, (b) spiral, and (c) whirl nozzles.

A detailed search for an acceptable commercial centrifugal atomizer was made. As a result of this search a Micronair (Aerial) Limited Model AU-3000 rotary atomizer was purchased and modified for stationary operation. Figure 2 is a sectional drawing of the unaltered AU-3000. The rotating screen impactor was equipped with a special mount and sheave such that power could be supplied from an electric motor (see Figure 3 for modification details). The original attachment block assembly (Figure 2) was removed. The brake disc assembly was removed and replaced with a sheave support plate (Figure 3). A minimum diameter sheave was machined and attached to the sheave support plate. The bearing bush was removed and replaced with a longer bushing to facilitate proper spacing for the drive sheave. The complete assembly was secured to a 0.5-inch thick magnesium support plate. Variable diameter sheaves permitted operation over a range of rotational speeds (3,000 to 10,000 rpm). A detailed laboratory study was made by Dow's Texas Division research personnel at Freeport, Texas during the period 10 Sep 71 to 17 Oct 71 inclusive, using the modified Micronair rotating screen impactor. The results are presented in Table 1.

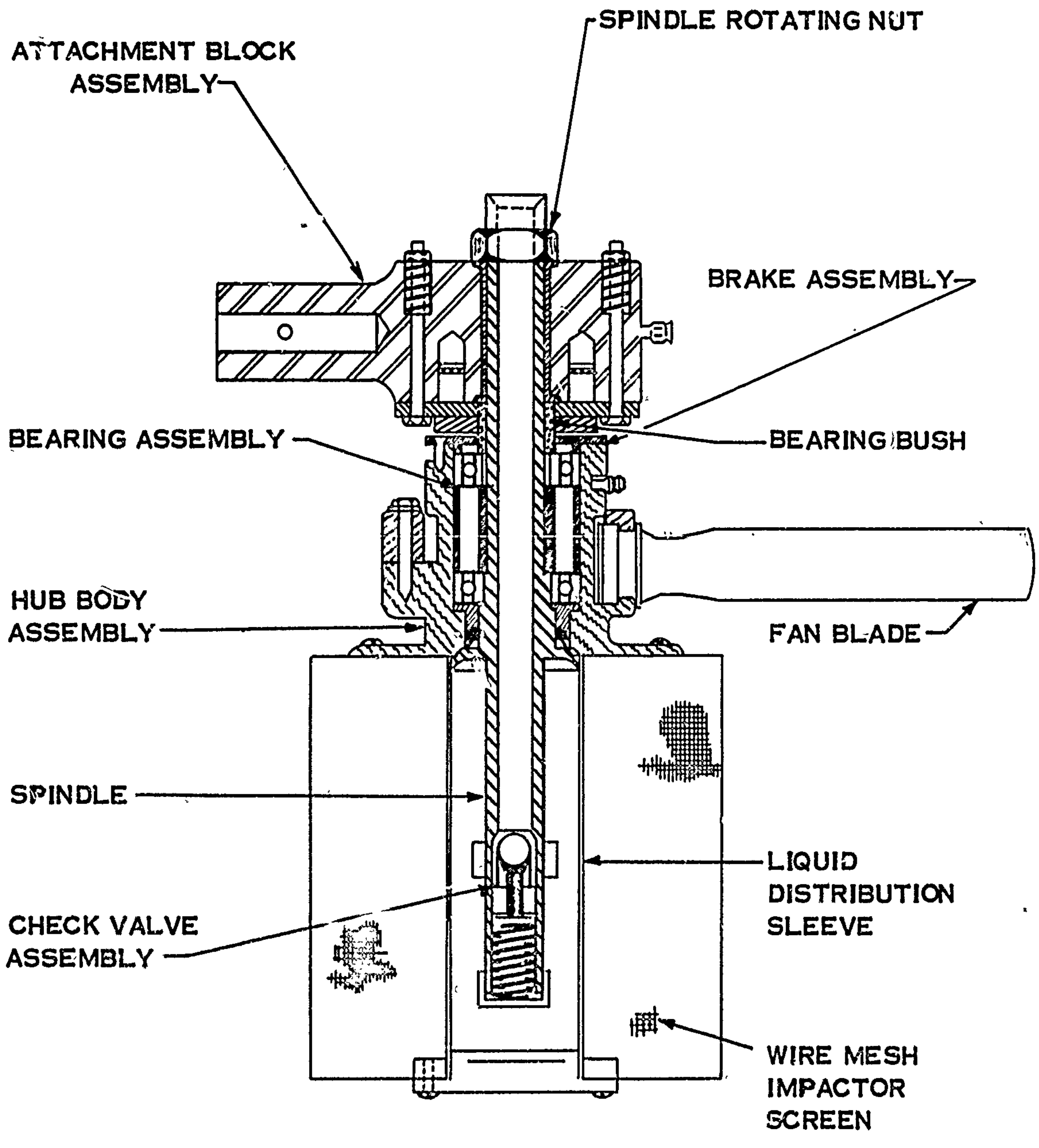

FIGURE 2. MICRONAIR ROTATING SCREEN IMPACTOR

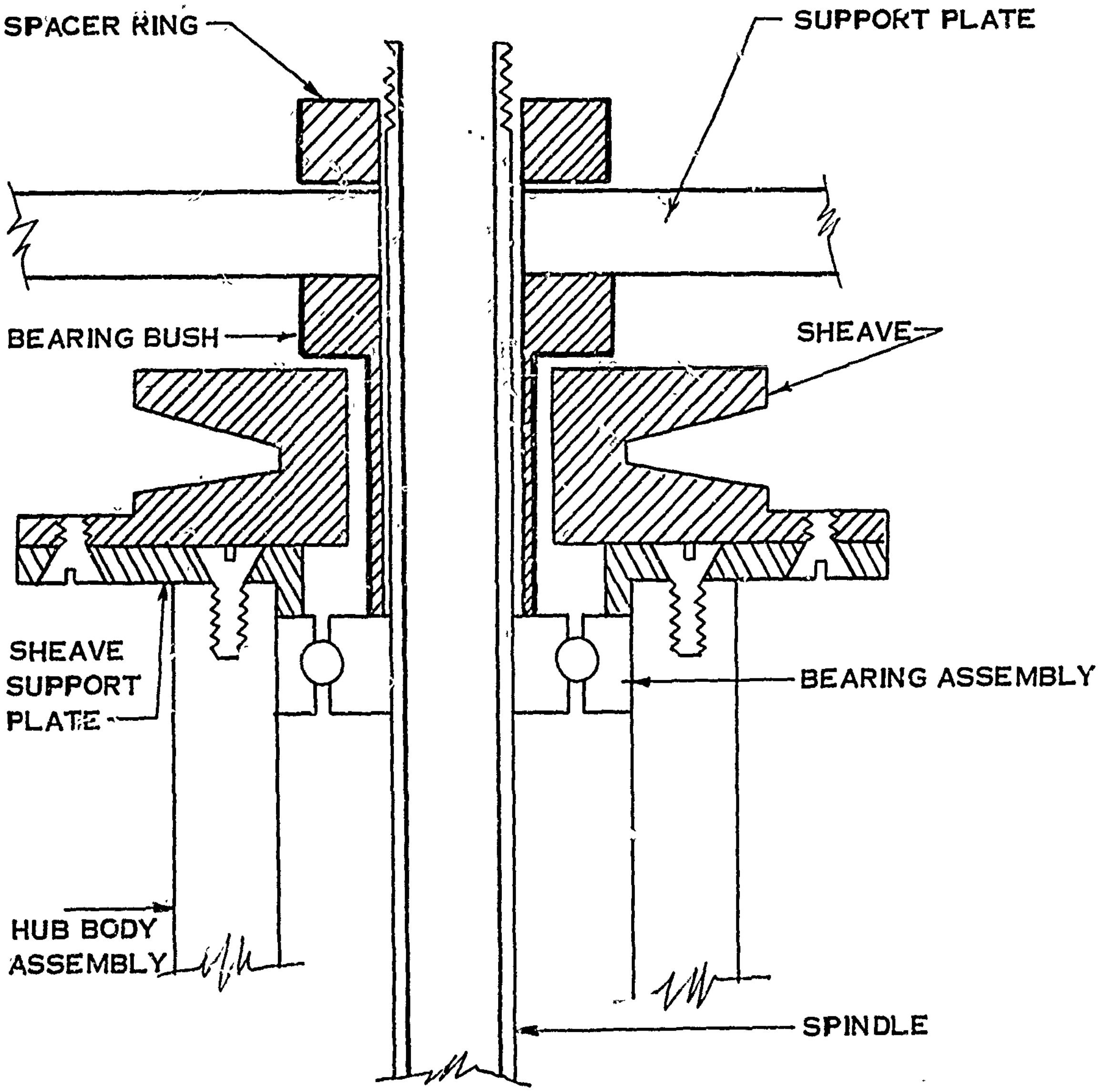

FIGURE 3. MODIFICATIONS MADE TO THE ROTATING SCREEN IMPACTOR SHOWN IN FIGURE 2

Disc Particulator

The centrifugal atomizers used during the Dow developmental studies evolved through three stages of development. The initial effort resulted in a workable atomizer which was used throughout one fog season in field tests at the Brazoria County Airport. This atomizer consisted of fifteen 4.5-inch diameter flat plates, each having a 1-inch center hole, separated by 0.010-inch spacers and stacked so the assembly could be rotated at speeds of 10-15,000 rpm. Liquids to be atomized were introduced into the cavity formed by the 1-inch holes in the center of the plates. The high viscosity liquids were filmed on the plate (under the influence of centrifugal force) and air-sheared into small droplets at the wheel periphery. That initial unit was used in proprietary field experiments and no particle size data were collected.

The design of the spinning disc atomizer used in the FOGGY CLOUD IV experiments resulted directly from the knowledge and experience gained from the earlier work. Initially, the atomizer was composed of only one 8-inch diameter disc. As finally developed, it consisted of six 8-inch diameter discs at 0.5626-inch center line to center line plate separation, or 0.328-inch separation between plates. The plates are mounted on a 1-inch outside diameter hollow spindle (see Figure 4). The disc assembly and support are designed to permit high speed (12,000 rpm) rotation.

Power is supplied by a 1.5 HP electric motor thru an adjustable size sheave, belt-coupled to the particulator sheave. Liquid is introduced through a special high speed rotary coupling (Item 1) to the hollow spindle (Item 6). The feed rate is controlled by pressure drop across sized orifices (Item 12) in the rotating spindle. The orifice discharge is channeled (Item 13) to a special groove (Item 15) in a spacer plate which by uniform overflow (16) evenly distributes the liquid onto the particulator disc (10). The disc surfaces are machined and polished to a mirror finish. Liquid deposited on each disc is filmed to a uniform thickness at the disc periphery which is carefully machined to form a knife edge at the mechanical separation line (17). The liquid film leaving the disc at high calculated tangential velocities (100-200 ft./sec.) is broken up into uniform droplets. The mean drop size and size distribution is influenced by the solution viscosity and density. The drop size can be controlled by the rate of liquid feed and by the speed of rotation of the particulator. The overall dispersant flow capacity is determined principally by the number of discs employed. There are, however, a number of other design parameters which can influence the generation capacity, for example (1) the drive motor horsepower, (2) the flow limitations of the liquid feed tubing, (3) the viscosity of the dispersant chemical, etc.

During September and October, 1971 a detailed study was conducted at the Dow research laboratories (Texas Division, Freeport, Texas) on a single disc unit. This study was made in partial fulfillment of the proposed work plan*, Section 1.-a. 3 and 4, page 21, which are quoted on page 12 of this report.

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*Volume I, Dow Chemical Company Technical Proposal 77181, "Warm Fog Dispersal Study Utilizing Polyhydric Organic Compounds."

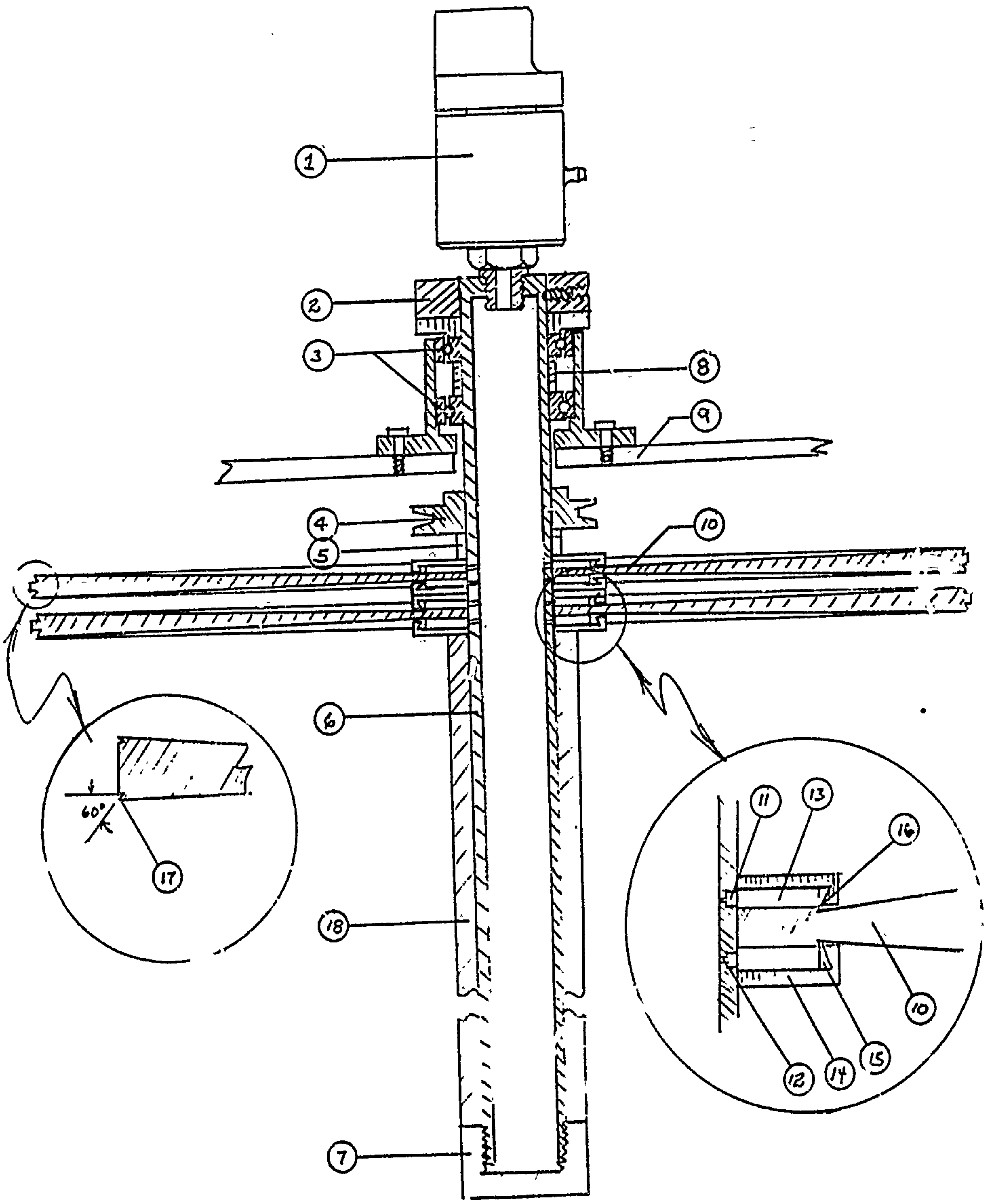

FIGURE 4. DISC PARTICULATOR

KEY TO DISC PARTICULATOR PARTS FOR FIGURE 4

Item No.	Description
1	High Speed Rotating Union
2	Bearing Assembly Retainer
3	High Speed Bearing Assembly
4	Drive Sheave
5	Spacer
6	Rotating Arbor
7	Disc Assembly Retainer Nut
8	Bearing Spacer
9	Support Frame
10	Rotating Disc
11	Arbor-Liquid Distribution Channel
12	Liquid Feed Orifice
13	Liquid Channel
14	Disc Spacer
15	Disc Spacer/Liquid Distribution Channel
16	Weir
17	Knife Edge-Liquid Mechanical Separation Line
18	Arbor Spacer

"3. Select or furnish best dispersion system available."

"4. Modify dispersion system to obtain the desired particle size (10 to 100 μ)."

"Develop particle size measurement and control for this system."

Results of the detailed laboratory study made on the single disc unit are reported in Table 3.

TABLE 3.

DISC CENTRIFUGE PARTICULATOR LABORATORY DATA USING GLYCERINE

Run No.*	Speed, (≃ rpm)	Temp., (°C)	Flow Rate (ml/min.)**	Laboratory Data Using Glycerine: Particle Diameters, Microns§ Low	Mean	High	Particles Counted
31-1	9000	25	100	17	29	46	371
31-2	9000	25	600	38	58	100	409
31-3	9000	28	800	20	37	64	449
31-4	9000	28	2400	26	58	96	432
31-5	5600	26	240	17	29	53	209
31-6	5600	27	500	13	29	66	311
32-7	5600	27	200	27	37	68	276
32-8	5600	25	200	30	55	86	457
33-1	9000	32	400	18	38	66	375
38-1	9300	23	220	27	51	67	435
38-2	9300	25	500	27	58	83	411
38-3	9300	28	700	20	29	61	425
40-1	6400	33	3735	7	21	67	542
40-2	6400	35	2050	17	43	65	388
40-3	5000	38	2050	15	29	85	455
41-4	5000	38	3735	17	46	75	399
41-5	8000	37	3735	12	41	62	390
41-6	8000	37	2050	10	35	69	492

*All data recorded in book number 13135, Dow Chemical U. S. A., Texas Division.
Runs 31-1 thru 38-3, inclusive, used a single-disc particulator.
All other runs (40-1 thru 41-6, inclusive) used the 6-disc assembly shown in Figure 3.

**Ml/min. is milliliters per minute glycerine flow.
§ Figure 1 explains the particle diameters in Table 3, above. These droplets were collected on 1" x 3" Teflon-coated microscope slides, held approximately 30" from the atomizer for about 15 seconds. The droplets were then counted under a microscope in a calibrated field.

EQUIPMENT USED IN FOG DISPERSAL TRIALS

The equipment taken to California for the fog dispersal tests was calibrated at Arcata/Eureka Airport.

The first five equipment-test runs made by the Dow project team (Table 4) were to reassure the satisfactory performance of the particulation equipment and all its related accessories.

Captioned photographs are provided to illustrate the nature of both the equipment available through FOGGY CLOUD IV and the Dow equipment. Some of the photographs were taken originally in black and white and others in color. A few used black and white Polaroid[R] film. Reproduction of some of these prints in this report has not resulted in as much clear detail as we would like. The List of Photographs at the front of this report shows the original type of print for each photograph.

TABLE 4. FOG DISPERSAL EXPERIMENTAL DATA

Run No.	Date	Time	Clear Air or Fog	Fluid Temp., (°C)	Wt., Lbs.	Vol., Gals.	Flow Rate: Set: Press. psig	Flow Rate: Set: GPM	Flow Rate: Calc.: Lbs./Min.	Flow Rate: Calc.: GPM	Run Time, Sec.	Elev., Feet	Remarks
1	10/19		Clear		27	2.57	40		9	0.8571	180	0	Calibration test.
2	10/19		Clear		14	1.33	75		13.6	1.2903	62	0	Calibration test.
3	10/20		Sl Fog			15	30					30	Balloon equipment trial.
4	10/23		Clear									0	Demonstration (run on ground).
5	10/[illegible]		Clear		24	2.29	75		4.4	0.4194	327	0	Flow calibration test.
6	10/30	2300	Fog		130	13	75					10	Between vans using blower.
7	10/30	2400	Fog									10	Repeat Run 6 for searchlight photos.
8	11/2	945	Clear	50	14	1.33	25		28.0	2.667	30	100	To see where mist would fall.
9	11/2		Clear	50	126	12.00	25		28.0	2.667	270	100	To collect particle samples.
10	11/2		Clear	26	140	13.33	20		28.0	2.667	300	100	
11	11/2		Clear	23	64	6.85	50	1.4	6.6	0.7866	585	100	Tetraethylene glycol
12	11/2		Clear	33	41	4.41		2.3	9.4	1.121	263	100	Diethylene glycol
13	11/3	1015	Clear	30	10	0.95	50	0.9	2.0	0.1905	300	100	Rotating screen impactor.
14	11/3	1057	Clear		150	14.29	100	2.5	18.1	1.725	497	100	Rotating screen impactor.
15	11/4	0948	Fog*	30	84	8.00	20		9.0	0.8571	560	450	FOG TEST

*Air temperature at beginning of Run 15 was 3°C.
Runs 1, 2, and 3 were at Arcata/Eureka Airport. All others at Redwood Valley, California.

Most of the experimental data above were collected using glycerine in the rotating disc particulator (6 discs) operating at 6600 RPM. Runs 11 and 12 used tetraethylene glycol and diethylene glycol, respectively. Runs 13 and 14 used the rotating screen impactor at 5600 and 6000 RPM, respectively.

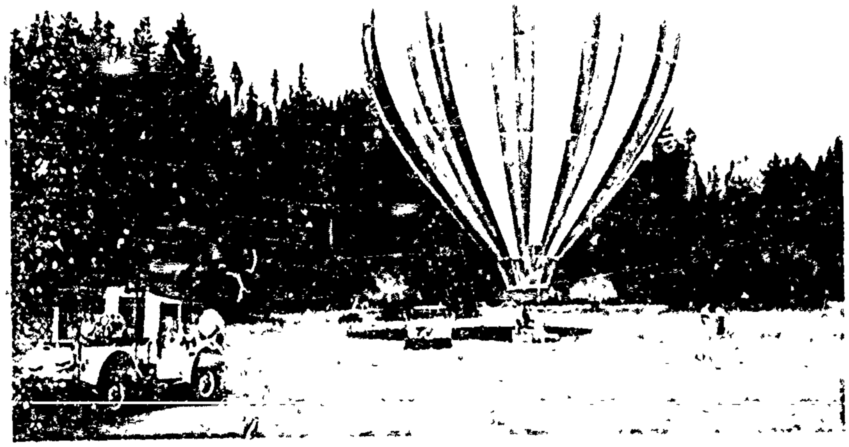

Photo 1. Redwood Valley. The tether truck (with searchlight on front fender) and hot-air balloon.

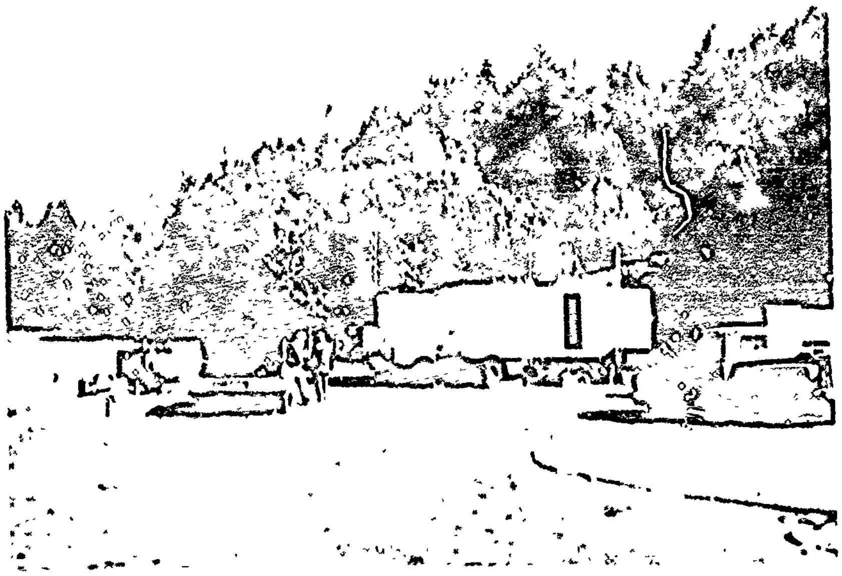

Photo 2. Instrument equipment vans and other accessory devices.

Photo 3. Diesel power generation equipment.

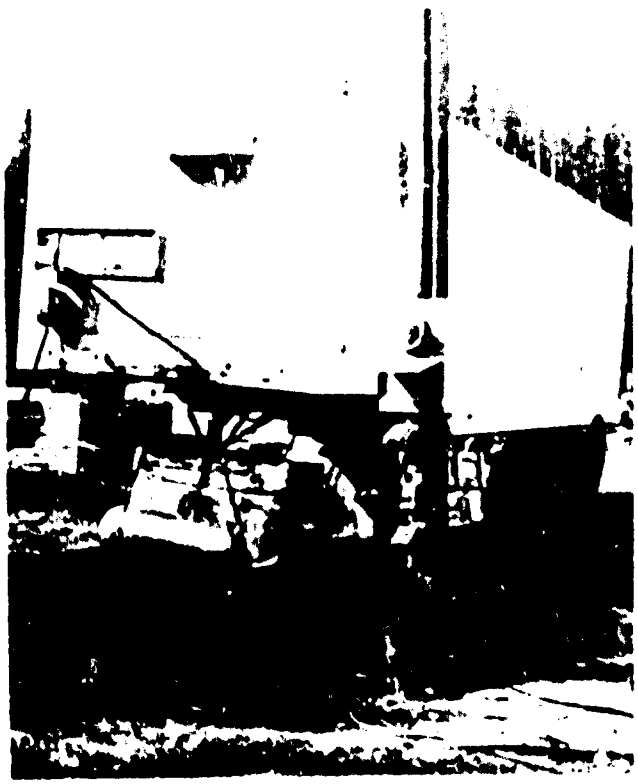

Photo 4. Meteorological van. Dow fog dispersal equipment stored under the front of the van. Power pole in foreground.

Photo 5. Disc particulator generating mist. Collecting a sample on microscope slide for particle size distribution count.

Photo 6. Particulator in operation, showing the rotating discs.

Photo 7. Particulator drive with the rotating screen impactor mounted on it.

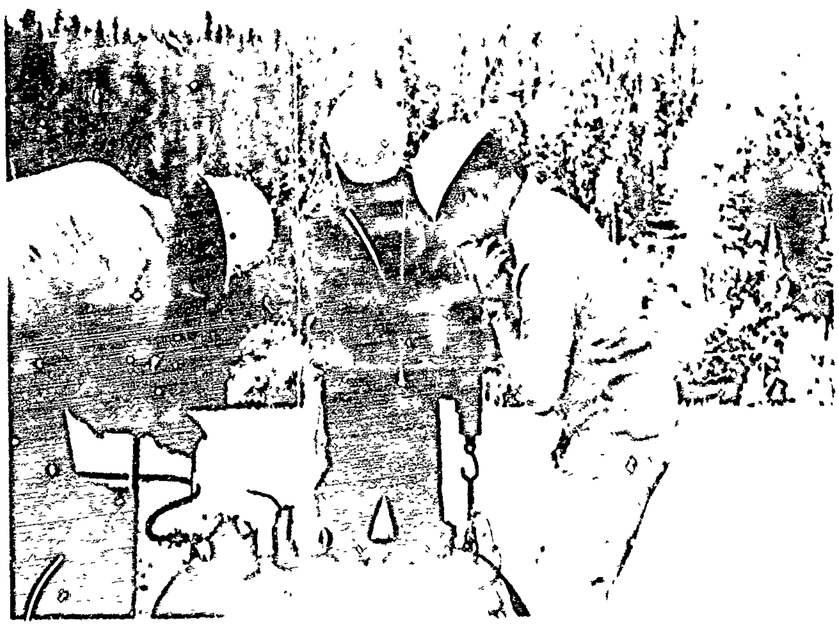

Photo 8. Weighing the supply tank of treating fluid. Note the bubble level on top of the tank.

Photo [illegible]. [illegible] Airport. The disc part [illegible] just lifting off the pad ([illegible] support lines).

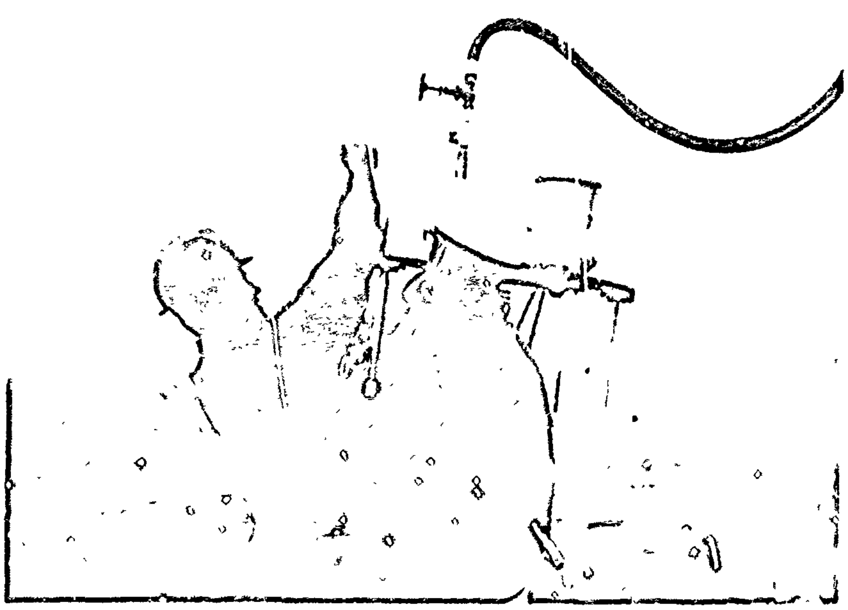

Photo 10. Adjusting support lines on the particulator.

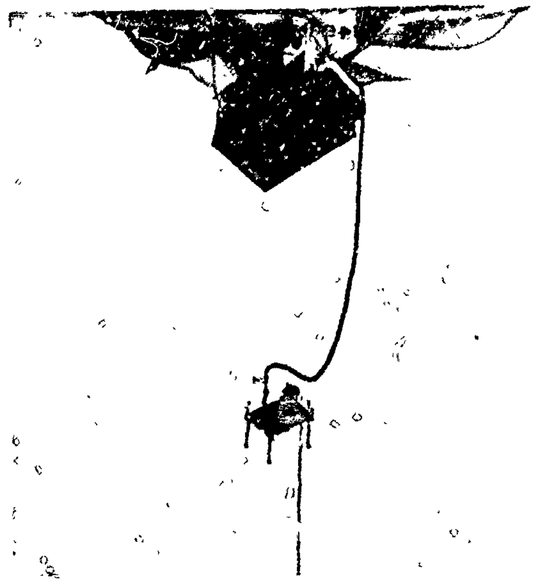

Photo 11. Particulator platform aloft, supported by the hot-air balloon gondola.

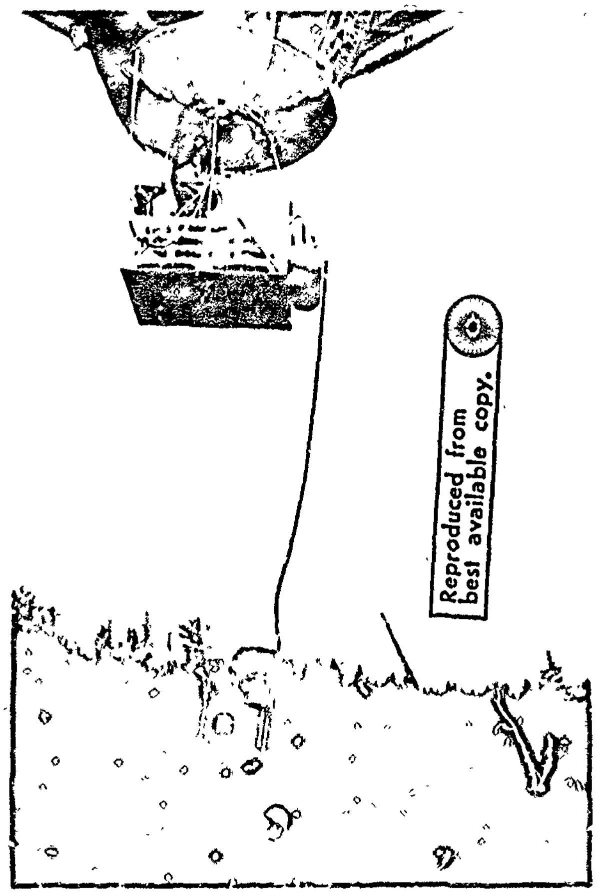

Photo 12. Rotating screen impactor aloft.

CLEAR AIR TESTS

A series of clear air (no fog) tests were performed in Redwood Valley on 2 and 3 November 1971. There was very little time left to wait for fog and these would at least provide evidence of equipment capability. These tests also later proved to be valuable for an understanding of the fog trial results obtained on 4 November.

Before each of these trials, the temperature of the dispersant chemical and its flow rate were determined. The supply tank was then weighed to find the initial gross weight of tank and contents. After each run the tank was re-weighed. The amount of chemical used was determined by weight difference.

All the runs made on 2 November used the disc particulator. The first two runs (No. 8 and No. 9 in Table 4) were made using warmed (50°C) glycerine and 25 psig helium pressure in the vapor space of the supply tank. The glycerine had been standing in the supply tank over two light bulbs all night to keep it warm because cold glycerine is very viscous. The spray equipment was lifted by the hot-air balloon to an altitude of about 100 feet above ground level for each of these runs.

Run No. 8 was a 30-second burst of liquid with the discs turning at 6600 rpm. This first test was designed to determine where the cloud of droplets would drift (see Photo 13). Run No. 9 was a 4-minute, 30 seconds test to collect samples on the droplet detectors /1/ and to gather data (including photos) on the shape of the dispersant plume. The plume of mist from the warmed glycerine was comparatively dense (Photo 14). The plume was wide at the top and came down like a very slow motion waterfall. A large amount of the mist floated upward toward and around the balloon (Photo 15). The cloud of droplets coming off the particulator shifted and floated away in the direction of the breeze. In the breeze, the droplets became a long, horse-tail shaped spectrum of different particle sizes floating down at different distances from the generating device. This was caused by the varying fall rates between smaller and larger droplets.

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1. Two methods of drop collection were employed in the slide study: (a) impingement caused by forced air displacement of the droplets, and (b) impingement caused by gravitational sedimentation. In the forced air technique a sudden burst of ambient air is directed through an orifice onto a gel-coated slide. Entrained droplets in the air sample are caused to impinge on the soft gelatin coating resulting in surface deformation. A microscopic examination of the impact area can then be made to reveal quantitative information on both the droplet size and the number per given volume of air. Impaction by gravitational sedimentation differs only in the sampling technique. Falling droplets (under the influence of gravitational pull) are allowed to settle on exposed gelatin-coated slides. The droplet impaction causes surface deformations in the soft gelatin. These slides are later subjected to microscopic examination.

Photo 13. Run 8.

Photo 14. Run 9.

Photo 15. Run 9.

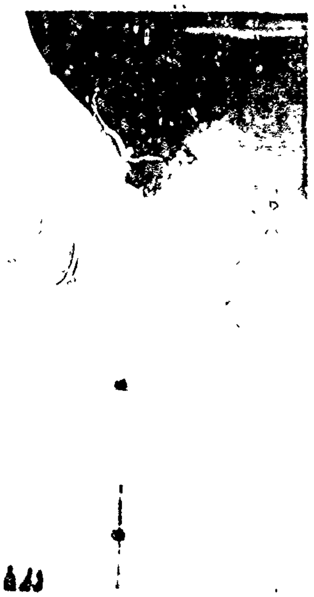


Photo 16. Run 10.

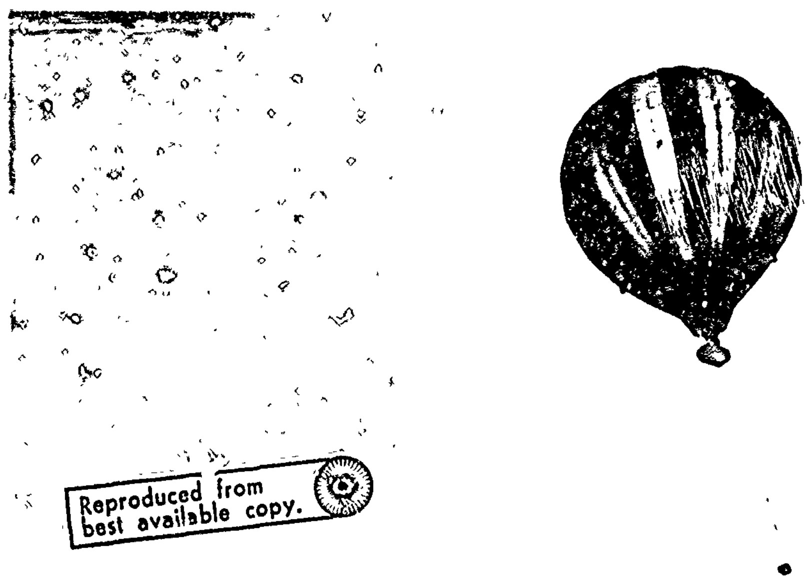


Photo 17. Run 10. Notice the white wisps of chemical dispersant on the left of the picture.

The third run (No. 10 in Table 4) used 26°C glycerine and 20 psig helium pressure. The cloud of droplets this time seemed less dense and appeared to be composed of finer particles and they remained suspended more so than during the earlier shots. The change in viscosity evidently caused less glycerine to flow across the discs, and as a consequence there was a thinner layer of material, which resulted in smaller particles. This run lasted 5 minutes, used 20 psig helium pressure, and consumed 140 pounds of chemical which is 2.667 gallons per minute flow rate (see Photos 16 and 17). Photo 17 shows how the dense cloud of dispersant chemical spreads laterally at the disc particulator then later becomes vertically distributed. These wispy trails of droplets moving sidewise in the wind field, slowly separate vertically because of drop size differences. The patterns created by these curtains of droplets remain in motion and as they spread they become less and less visible.

The fourth clear air test (No. 11 in Table 4) used tetraethylene glycol at 23°C and 50 psig helium pressure. For this run the valve mounted just above the particulator in the liquid supply line was partially closed to set the flow at 1.4 gallons per minute. During the actual in-flight particulation, the flow rate was 0.787 gallon per minute.

The cloud of droplets generated by the tetraethylene glycol in the disc particulator was quite similar in general appearance to the plume using glycerine. The cloud of droplets appeared to spread rapidly to about a 10-foot diameter and then moved away horizontally in the wind field. At about 100 feet of drift, the width of the droplet pattern was about 20 to 25 feet. In this wind field (2 or 3 knots) the first particulate appeared to hit the ground about 80 feet downwind of the equipment (100 feet high) and fall-out extended to 300 feet or so downwind. The floating cloud remained visible for about 150 feet downwind.

Diethylene glycol at 33°C was used in the final particulation run on 2 November (No. 12 in Table 4). The valve just above the particulator was again partially closed to provide the desired flow of 2.3 gallons per minute. During the in-flight operation the flow was 41 pounds or 4.41 gallons in 4 minutes, 23 seconds. This was a calculated flow of 1.12 gallons per minute. The droplets coming off the particulator looked very similar to those in the previous run. The droplet cloud was about 10 feet across at the particulator and it spread and fell in filmy cascades downwind of the apparatus (similar to Photo 17). There was a visible cloud for some 300 to 400 feet this time.

Upon completion of these five tests, the supply tank was completely drained and refilled with glycerine to be ready for use the following day.

The clear air tests were completed on 3 November. The first trial (No. 13 in Table 4) used the rotating screen impact particulator. The rotation rate was changed to 5600 rpm and the 30°C glycerine was pressured to 50 psig with helium. The rotating screen on the atomizer mechanism is designed to be operated at lower rotation rates than the disc particulator. At higher rates (>6000 rpm) it could throw off the screen. This is why the rotation

speed was reduced from 6600 rpm when this particulator was operated. The liquid supply line valve was controlled to a flow of 0.9 gallon per minute (gpm). During the actual in-flight operation only 0.95 gallon was used in 5 minutes of running time. This calculates to be only 0.19 gpm and would explain the smaller size of the cloud of mist coming off the particulator. There was a substantial amount of the liquid in heavier or larger particles falling rapidly right under the apparatus caused by impact coalescence on the equipment. There was also evidence of very fine mist being generated. It is thus concluded that this device makes a wider spectrum of particle sizes than the discs.

The second trial on 3 November (No. 14 in Table 4) again used the rotating screen impactor. The rate of rotation was raised to 6000 rpm to improve the generation of fine particles. The helium pressure on the glycerine was increased to 100 psig and the flow rate was set at 2.5 gpm. During this flight, the rate of flow was 1.73 gpm.

The cloud of droplets this time also showed the wide spectrum of particle sizes. The 20-second falling time from 100 feet altitude indicates 100 micron maximum particle size (see Table 1 in the Appendix). The fine cloud of droplets that floated away on the breeze was 20 microns or less in diameter. The cloud of droplets was about 6 feet in diameter at the particulator and as it floated away it was visible for some 100 feet. After this trial, the equipment was cleaned and the disc unit was put back on.

Particle collection below the balloon was not accomplished because (1) the wind blew the lighter particles away, thus the desired measurements could not be obtained, (2) coalescence on the airborne equipment caused large drops to fall onto the collection equipment and personnel.

Particle collection in the field was not acceptable because the hand-held slides could not be placed in a meaningful location downwind of the balloon. Up close, the particles that struck the plate were only the large, rapidly falling droplets. Farther away, the droplets were much smaller. In addition, since there was a long delay before the particles began to reach the ground (due to their Stokes falling rates), it was difficult to collect a meaningful sample because of the differences in fall rates. Highly variable winds during these tests considerably complicated the droplet sample collection. Subtle changes in the direction caused the hand-held sample plates to have only a very slim chance to be directly in the path of the falling droplets of dispersant.

FOG COALESCENCE GROUND TRIAL

This experimental trial was conducted on the evening of 30 October through the early morning of 31 October. Since fog had not been expected to occur in Redwood Valley during this evening, the FOGGY CLOUD project team was not on standby for conducting tests. Otherwise, a standard hot-air balloon-borne fog dispersal test would have been conducted. Instead, a method was devised to collect data using the equipment on hand that Dow personnel could operate.

By about 10:00 P.M. PST on 30 October a low to moderate density fog had built up and persisted for an hour or more. From a location near the meteorological trailer (also called the "Met" van), the incandescent lights in a residence about 350 feet away were visible but pale yellow and partially obscured. The moon (approaching full moon phase) was obscured to near extinction.

To perform this fog coalescence trial, the disc particulator apparatus was suspended between the two trailers ("Charley" van and "Met" van) as shown in Figures 5, 6, and 7 and in Photo 18. The apparatus was supported by four 3/8" diameter hand lines thrown over the vans and tied at opposite sides of the vans. The discs (which were about 8 to 9 feet above the ground) were placed at an angle that caused their plane of rotation to be parallel to the air blast from a blower located on the ground about 25 feet from the particulator. The squirrel cage blower had about a 16" x 19" outlet port and was driven by a small internal combustion engine. The air blast (angled upward from the ground about 30 degrees) was aimed carefully to strike the discs and then flow up and out (away from the vans) into the foggy open area aft of the vans.

The feed line for the dispersant chemical (glycerine in this case) was led from the supply tank (sitting on the ground) up to the particulator. Helium pressure in the dispersant supply tank was set at 75 psig. Disc rotation speed was 6600 rpm. Feed flow rate of glycerine was about 0.4 to 0.5 gallon per minute during the two runs that were made. One hundred thirty pounds (13 gallons) of glycerine were dispensed during the first of the two trials.

During the trials a number of different observations were made of the characteristics of the surrounding fog and of the treated fog. The surrounding fog maintained its opacity or density and waned very slowly toward the end of the two hours during which the trials were conducted. There was a light air movement (0.5 to 1.0 knot) up the canyon (toward the south) the whole time.

With the particulator and the blower both running, the treated area (as shown in the General Plan View, Figure 7) of the fog showed four different conditions. Each occurred at different distances from the particulator. Out to 15 or 20 feet was a heavy, coalescing mist. From there to about 50 feet was "rain" or droplets of sufficient size that they were falling like rain. Beyond the rain for an indeterminate distance was an irregular tunnel of cleared air in the fog. This was followed (about 50 to 70 yards further out) by the closing in of the surrounding fog. The tunnel of cleared air in the fog was most readily seen where it intersected the beam from the large spotlight. The light scatter (Tyndall Effect) in the fog was bright and would be easily photographed with proper equipment and skill. Any cleared areas in the fog leave discontinuities in the light path. The five Polaroid photographs, 19 thru 23, show the appearance of the spotlight beam in various circumstances. These photographs are not representative of the degree of fog modification seen by the Dow project team and the other two observers present.

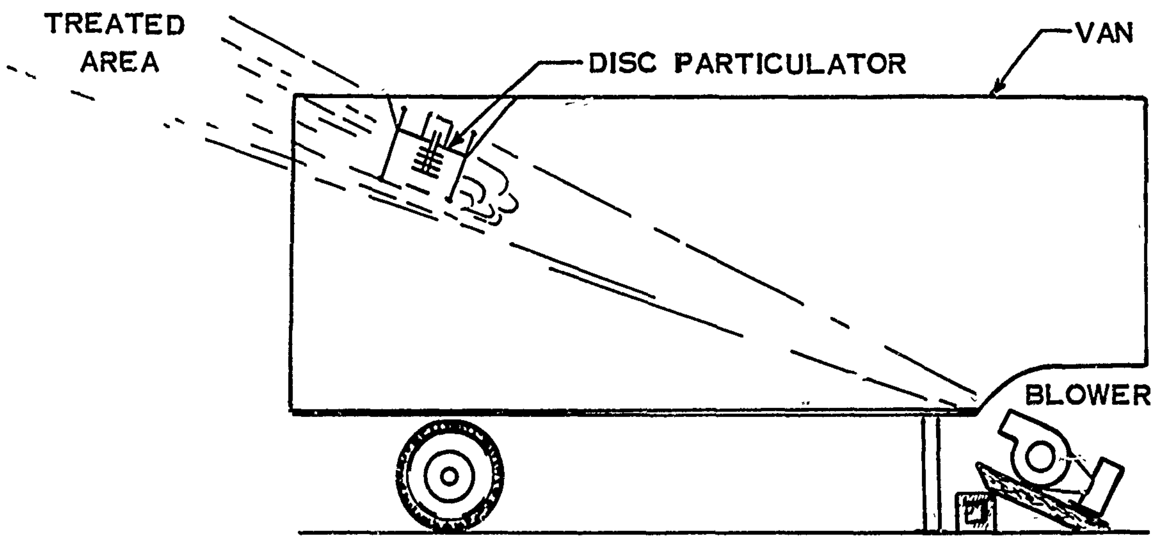


FIGURE 5. FOG COALESCENCE GROUND TRIAL EQUIPMENT
(SIDE VIEW)

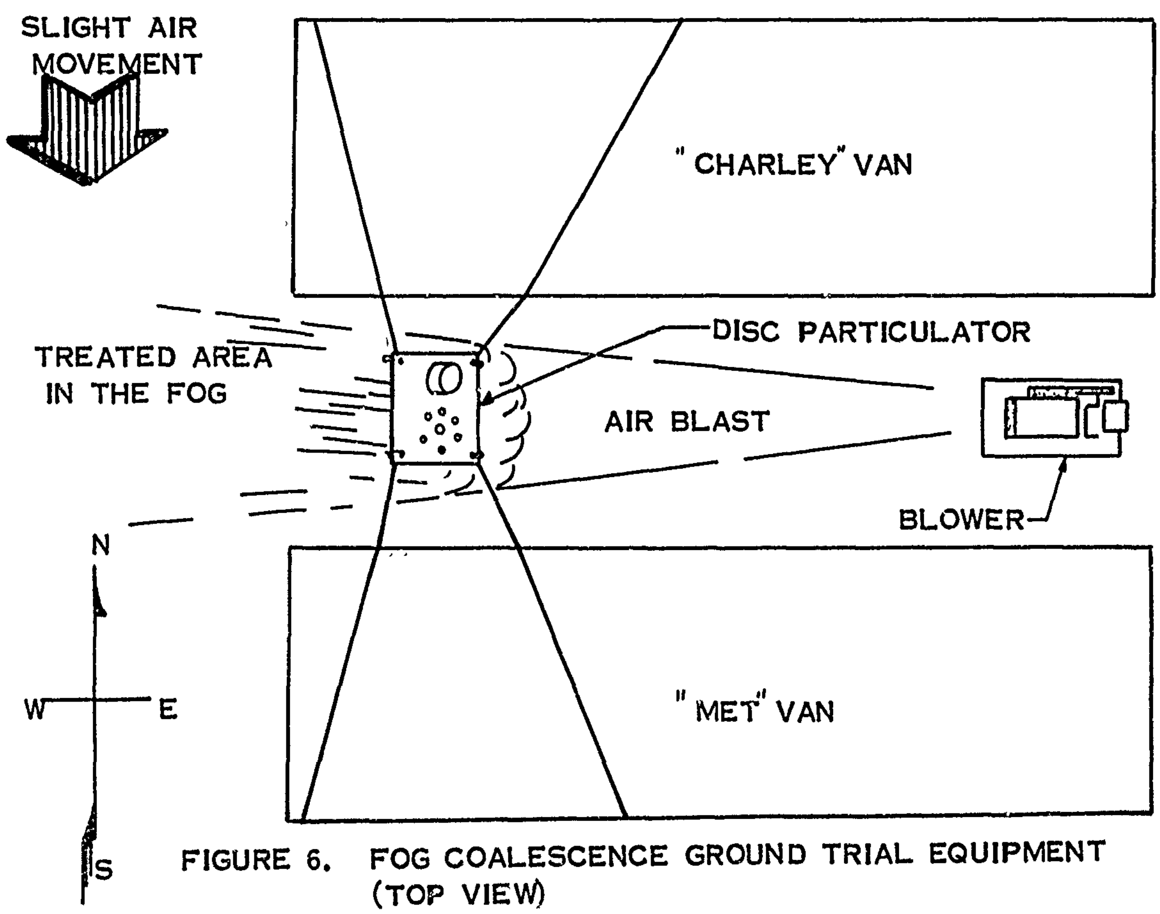


FIGURE 6. FOG COALESCENCE GROUND TRIAL EQUIPMENT
(TOP VIEW)

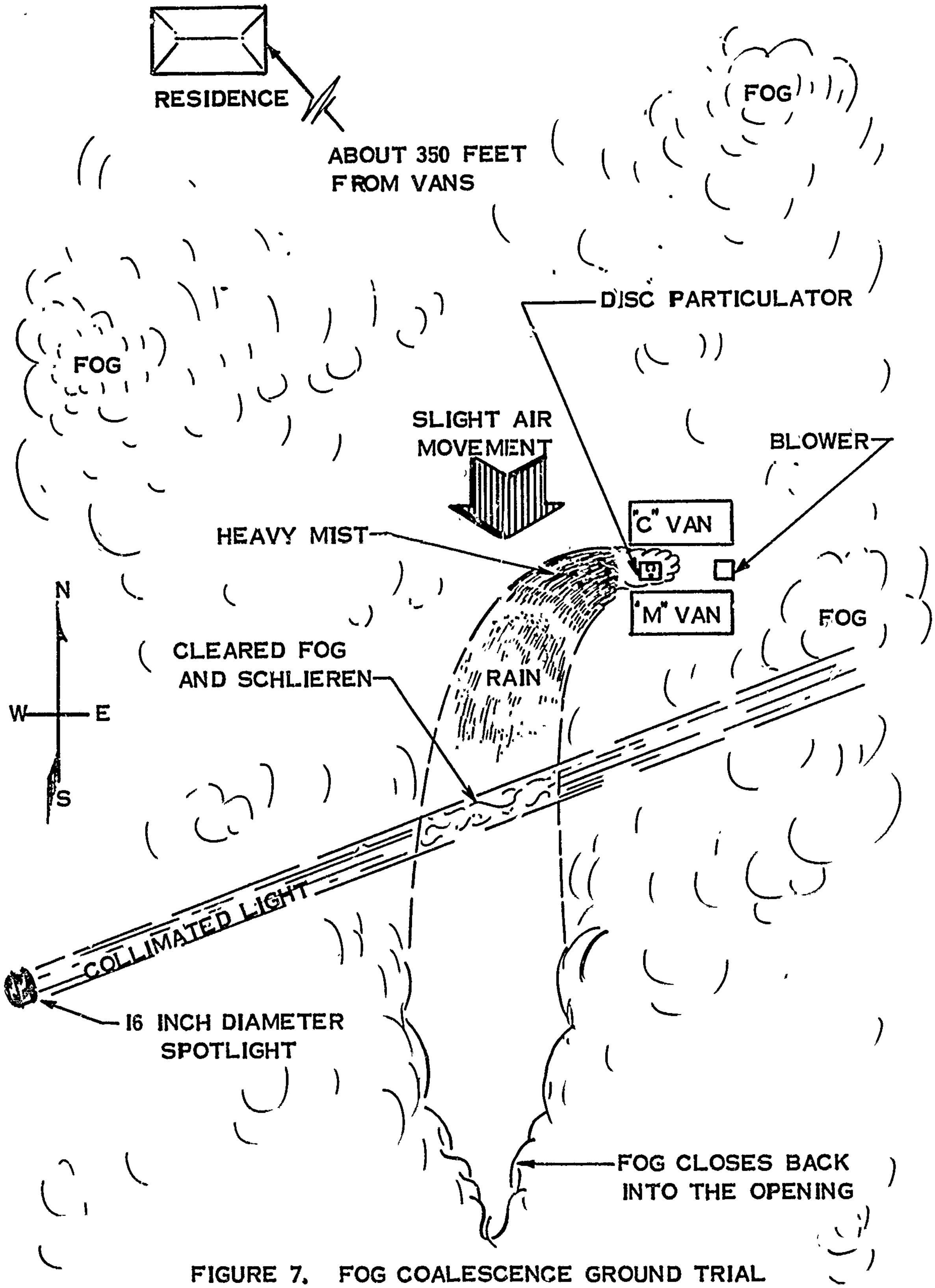


FIGURE 7. FOG COALESCENCE GROUND TRIAL GENERAL PLAN VIEW

Photo 18. Disc particulator hanging between the two vans ready for operation. Note the blower in background and the dispersant supply tank in the foreground.

Photo 19. 24 Oct 71. About 11:30 P.M. PST.
Searchlight beam in untreated fog.

Photo 20. 24 Oct 71. About 11:30 P.M. PST.
Searchlight beam with schlieren from diesel generator exhaust cutting the light path (left and center).

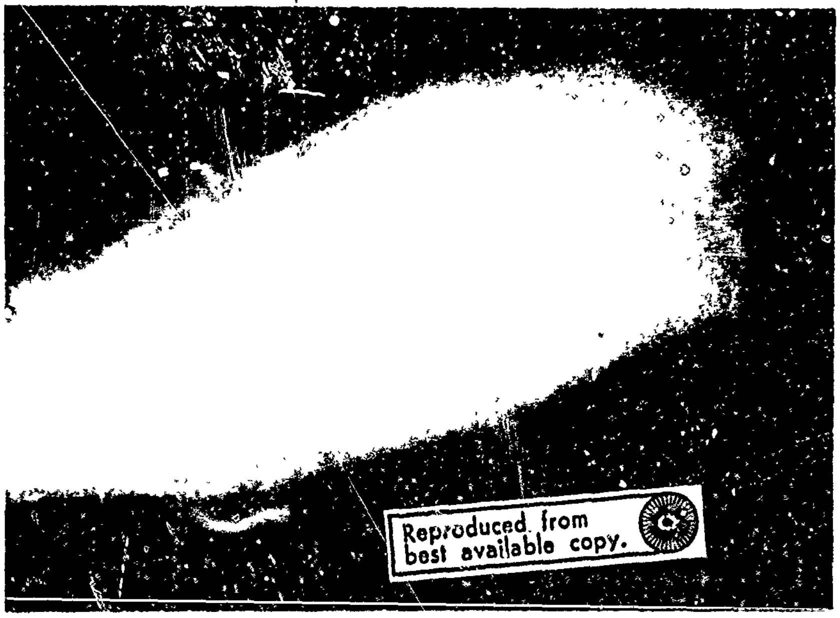


Photo 21. 31 Oct 71. About 12:02 A.M. EST. [illegible] about 2 min. after treatment of fog with particulated glycerine began. Note striations in grayish part of beam (far right).

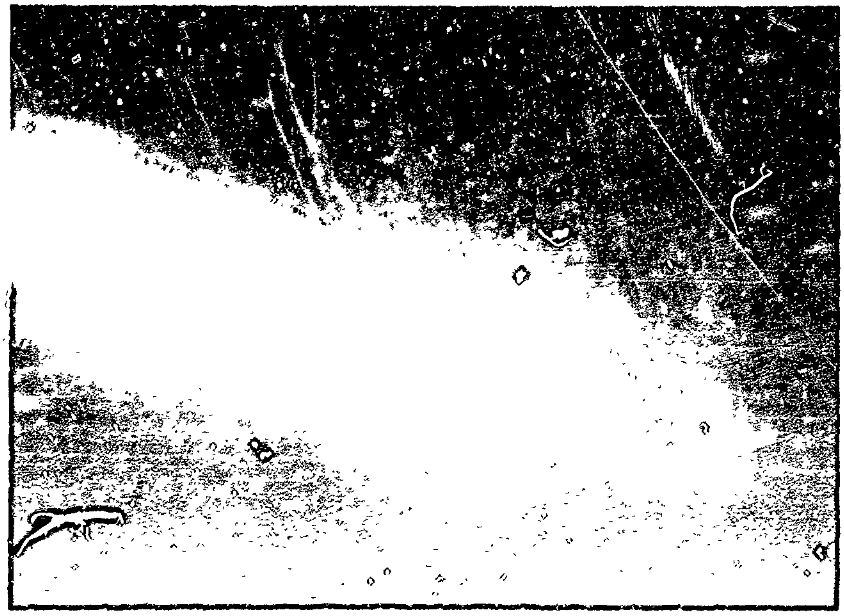


Photo 22. 31 Oct 71. About 12:[illegible] A.M. [illegible] search-light beam after [illegible] disturbed areas of beam and [illegible] from Tyndall [illegible] (1[illegible]).

Photo 23. 31 Oct 71. About 12:30 A.M. PST. Fog has again become uniform in searchlight beam a few minutes after chemical treatment ceased.

FOG DISPERSAL TRIAL FROM HOT-AIR BALLOON

This experimental trial was conducted on 4 November 1971. The FOGGY CLOUD project team arrived in Redwood Valley about 8:00 A.M. and prepared for a balloon-borne fog dispersal trial using the Dow equipment. The sky was overcast with a >100-foot thick stratus layer with its base some 200 feet off the ground.

Although the sun was up (9:40 A.M. PST) there was no sunlight directly visible, nor was the position of the sun discernible through the layer of stratus. Fog at ground level was sparse. There was very little air movement and air temperature was 3°C. This high base fog (or low stratus) condition had existed for most of the night but dispersal experiments were not begun because the fog was not as dense as desired.

The disc particulator equipment was made ready and slung from the gondola of the hot-air balloon. As soon as the flow rate of the dispersant chemical (glycerine) was adjusted to the desired rate (9 lbs./min.) and the supply tank weighed, the equipment was lifted aloft below the hot-air balloon gondola.

When the equipment was 350 feet above the ground (at 9:47 A.M.), the power and the liquid feed were activated. The first effect noted, both from the ground and from the hot-air balloon, was the appearance of a darkened, streaky effect where the droplets went into the fog. This effect was similar to the dark, streaky appearance of a localized rain shower as seen from a distance. While the particulator continued to run, the Navy U-3 photographic plane was heard overhead, making its first pass for pictures. Photo 24 is the first picture taken from the ground. It illustrates the general gray of the overcast on the left and the first evidence of clear sky beginning to appear on the right side. Aerial photographs 139, 140, and 141 were made from above the test site at about the same time as Photo 24.

The aerial photographs shown were taken from a U. S. Navy U-3 aircraft flying at an altitude of 10,000 feet above ground level (AGL). These photos can be identified by their photo numbers which are all above 100. Each aerial photo shown enlarged by 4 (4X) is identified by the letter "E" preceding the number. This gives the scale and detail that would result if the photos had been taken from about 2,500 feet AGL. The feel for dimensions or scale can be improved by looking at Photos E199 and 199 which were taken after the fog layer cleared. The semi trailers and the 60-foot diameter hot-air balloon provide good references for scale.

A short time later (4 or 5 minutes), there were some definite openings in the overcast near the balloon. The next two pictures from the ground (Photos 25 and 26) show this opening with the sun breaking through the overcast. A change in wind direction caused this break in the overcast to be extended into a crescent-shaped opening on the south, the west, and the north of the hot-air balloon as the dispersant moved around to the south.

The crescent-shaped opening was estimated from the ground to be about 100 feet wide and about 250 feet long. Blue sky could be seen through the opening.

It was assumed that the hole would close if the particulation of dispersant were stopped and the balloon brought down to the ground. However, after the balloon came down, there was a general break up of the overcast and the sky became completely clear in about 60 minutes.

During and just after this run, droplets were observed coming down as far away as 1200 feet to the south of the test site. These droplets had been blown that distance even by the relatively slight air movement in that direction.

As soon as this test was concluded, the principle participants were interviewed and their reports are in the transcribed tape submitted to the F. A. A. under separate cover.

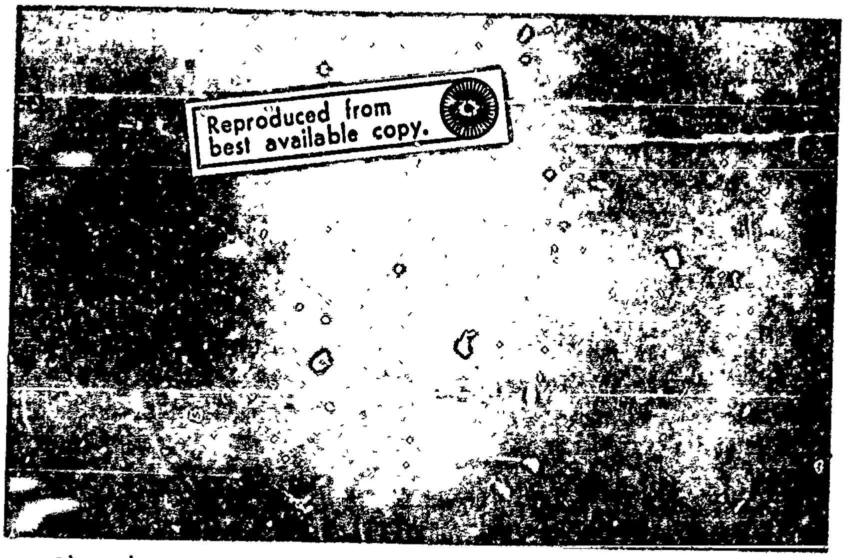


Photo 24. 4 Nov 71. General gray overcast. Meteorological balloon is top left, hot-air balloon center. Disc particulator in operation; dark overcast area on right is beginning to clear.

Photo 139. 9:51:30

Photo 140. 9:51:52

Photo 141. 9:52:10

Aerial photos taken from Navy U-3 aircraft. Note the 60-foot diameter hot-air balloon at the center of each photograph.

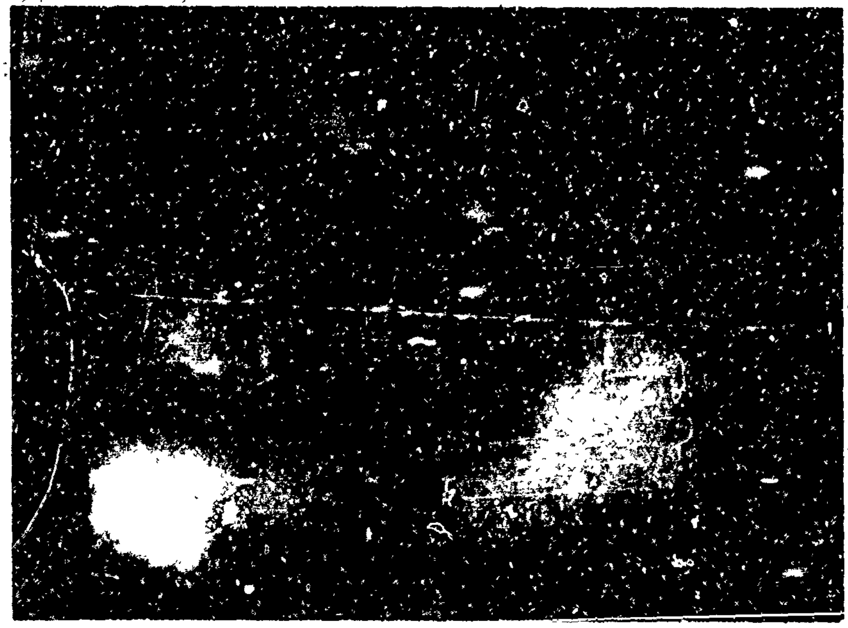


Photo 25. 4 Nov 71. Breaks are beginning to show as the particulated droplets cut holes in the overcast and the sun begins to break through.

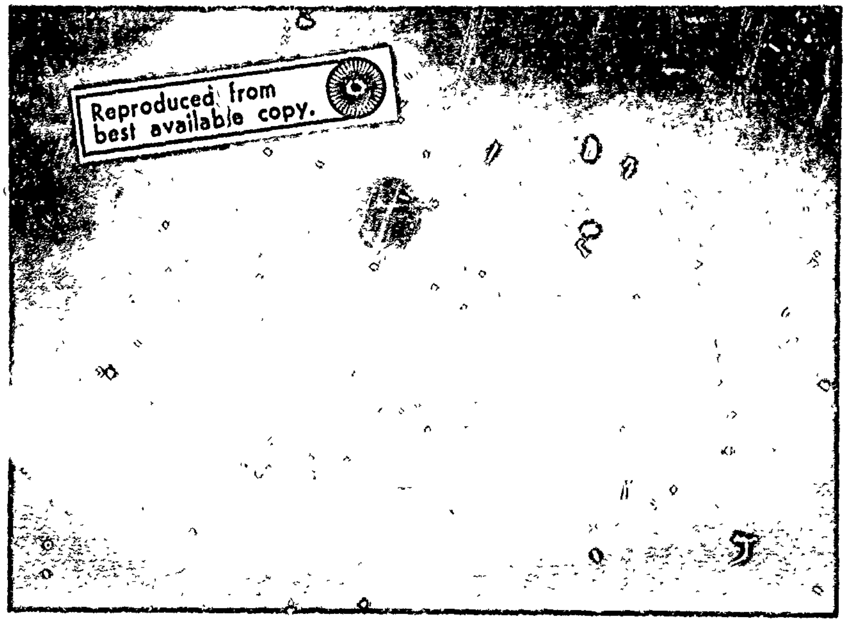


Photo 26. 4 Nov 71. Open areas become more pronounced. Both the hot-air balloon and the path of the particulated droplets are visible now and the cleared area has become a wide swath.

The following are condensations of some conversations extracted from the tape recorder notes taken on 4 November. The complete interviews are available from Systems Research and Development Service Headquarters, Federal Aviation Administration, 800 Independence Avenue, Washington, D. C. 20591.

Hot-Air Balloon Observer: At first, when it hit the fog it looked kind of smoky, it was unnatural, then it seemed to break right through. When the wind changed to the other direction, fog started coming where you already cleared it and it seemed to be clearing up in the new direction of the spray. So I'd say definitely it wasn't natural.

Interviewer: When we saw a general blue area up there, was this quite obvious from above as well?

Balloon Observer: Oh, yes, real obvious. It was very definite.

Interviewer: Was that pretty well all at the same elevation you were or was it below you?

Balloon Observer: Below us, generally below us.

Interviewer: Were you on top of the fog?

Balloon Observer: Almost on top of the fog, we could see the blue sky and the sun just barely coming through but we were still in it a little bit.

Interviewer: Could you tell how far away the mist was carried before it actually started dropping into the fog or was it in it already?

Balloon Observer: It was a little hard, but actually it seemed to be right up where the spray rig was.

Interviewer (speaking to the hot-air balloon pilot): What did you see?

Balloon Pilot: After we got on top you could see that it looked dark off to the direction the spray was blowing and then it just kind of got streaky and then broke up. Black streaks.

Interviewer: Black streaks?

Balloon Pilot: Yes. Dark. The fog was white except where this stuff was going, it was turning black--streaky.

Interviewer: What distance away was this and roughly what width? Could you tell?

Balloon Pilot: It fanned out pretty bad. More concentration, more effect. But as it fanned out I would say it went from 20' on out probably to 30' width. It tapered out as it went out as it blew to the

north. Then the balloon came around and the spray came around too and got into another off to the east. I couldn't see the streaks that we were talking about because we were right over the top of them.........

------end of the interview------

In addition, the written reports of this fog dispersal test are included here:

Observers' Written Notes for Test IV-1B - Run No. 15

Ground Observer (Project FOGGY CLOUD IV Meteorologist):

"The instrumentation cable is not being used because the glycerine has caused the 2 x 2 slide devices and the impactors to malfunction during the supportive (clear air) tests. The 2-3 knot wind flow would most likely prevent proper positioning of the cable in the plume. The glycerine spraying began at 0947:30 and lasted for 9 min. 20 sec. The balloon became more visible three minutes after the spraying began and a hole was opened through the fog by 1002. The hole remained about the same size until 1015; then the fog started breaking up throughout the entire valley. The area was clear by 1040."

Hot-air Balloon Observer:

"Wind flow was from the north at the start of spraying. When glycerine first made contact with the fog, an unnatural, dark, smoke-like haze resulted. Several minutes later clearing streaks appeared generally following the wind flow. These streaks widened until a hole appeared over 1/2 of the field below. The northerly wind flow gradually backed to westerly and finally to southerly. The cleared area appeared to follow the glycerine plume as it shifted with the wind flow. Although the fog was filling previously cleared areas, the area adjacent to the plume remained clear throughout the spraying."

Hot-air Balloon Pilot:

"The balloon at approximately 500 feet AGL (above ground level) was in the fog. At the start of spraying, the ground was occasionally visible. The winds were light and variable, moving the balloon from the west side of the field, through the south to the east side. Approximately 3 minutes after spraying began the fog began to turn black, then run in streaks and finally clear."

Navy U-3 Aircraft Pilot and Observer:

"0945 Climbout -- Coast to north and south clear -- inland valleys fog-covered.
0948 Begin spray.
0950 Fog beginning to break -- no longer solid.
0955 Fog breaking up from coast inland -- Redwood Valley fog breaking -- still solid in valleys to the east -- clear to the west.

0957 End spray.
1002 Low scud out over water -- coast still clear and Redwood breaking -- eastward still solid fog in valleys -- Hoopa Valley solid.
1008 Haze in all valleys to mountain top level -- fog top lower, est. 1600' MSL.
1010 Break up continues -- Redwood Creek now visible from 10K altitude.
1014 Fog remains fairly solid on both sides of Redwood Creek -- general fog breakup continues.
1017 Balloon on deck and visible from 10K altitude.
1022 Breakup continues.
1029 Conditions scattered over test site -- rest of valley clear.
1032 Clear directly over balloon and test site, more so than adjacent areas -- eastern valleys still solid fog."

EXAMINATION OF THE RESULTS (FOG DISPERSAL TRIAL 4 NOVEMBER 1971)

The observations and photographs from ground stations and observations from the hot-air balloon all indicate visible effects from the fog dispersal chemical striking the stratus layer. The hot-air balloon required about 200°F air temperature inside the bag to lift the equipment, the pilot, and the observer. Convection currents of air around the balloon would carry any surface heat up away from the balloon. This warmed air would raise the enthalpy of the ambient air above and near the balloon surface thus contributing to some fog droplet evaporation. Simultaneously, the burner was putting 1.63 pounds of water vapor into the air for each pound of propane that was burned. This contributes to a higher humidity in and (by transpiration) around the hot-air balloon and may contribute to fog stability. The cumulative effects of the hot-air balloon in fog are subject to a large number of inter-related variables (ambient air temperature, humidity, pressure, hot-air balloon temperature, etc.) each of which would contribute to fog stabilization or to fog dispersion. It was observed in this instance that their combined effects may have caused some fog dispersion above the balloon during its ascent. Once the balloon reached the hovering altitude, no particular effect that could be attributed to the hot-air balloon was observed in the fog layer. The observed effects of the chemical treatment are believed to be accurate judgments of fog dispersal but irrefutable proof becomes difficult when the test results are mixed with the natural phenomena and any effects contributed by the hot-air balloon. The observations made from the Navy U-3 aircraft are helpful to indicate there was an imminent breakup of the fog layer in Redwood Valley even as this fog dispersal test began.

To extract the fog dispersal effect due to chemical treatment out of the natural breakup and any hot-air balloon effect, enlargements were made of the early photographs made by the Navy U-3. In these pictures there are several breaks, streaks, and openings which indicate the anomaly created by the dispersant chemical. In each one of the enlargements, north is approximately at the top of the picture. Directions will be noted as on a clock with the balloon at the center (i.e., 12 o'clock is north).

In the enlargement Photos E139 and E140, there is at least one radiating fan of darkened area in the fog beginning to develop. These pictures were taken before the chemical treatment had stopped. There are two fan-like areas in E139 which appear at 7:00 and 10:00 o'clock. In E140 they have evidently closed together in a much larger fan just left of the balloon from 9:00 to 12:00 o'clock. In the enlarged Photo E141, the developed area of treatment seems to move away from the hot-air balloon toward 11:00 o'clock. In E144, the treatment has evidently created another distinct trench or valley running off at about 10:00 o'clock. Each of these more clear-cut areas of dissipated fog are probably due to whatever larger size particulate had fallen within the first hundred feet or so lateral distance from the balloon. Since it has already been observed (see Clear Air Tests) that the majority of the dispersant chemical appears to move away almost parallel to the ground, its effect should only become evident after coalescing with some material farther away from the balloon than these heavier dispersant particles.

In the full scale aerial Photos 144, 145, and 146, there is a very definite and well-developed crescent about 1000 feet long and about 500 feet from center to edge. It is about 200 feet across the open hole. This area is directly under and around the hot-air balloon and is well within the potentially affected area, as can be noted in Table 5. The table shows that even at 0.5 knot, the particulate would have been carried over 500 feet by 9:58, or at one knot, the same distance by 9:53.

It is presumed that since (1) the opening is as dark or darker than other surrounding breaks in the stratus layer and since (2) it is an anomalous shape (crescent) having dark streaks or cuts in it, that this is indeed the effect of the chemical treatment. Likewise, these photos 144, 145, and 146 fall directly in the midst of the chemical treating time. The aerial photos E199 and 199 are presented for orientation and scale comparison. They were taken after the fog dispersal run was completed.

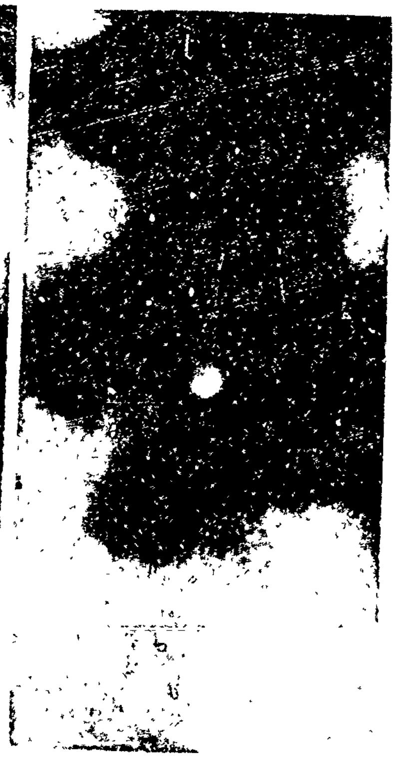
The main point is that there was a definite and noticeable improvement in the visibility through the fog layer within a few minutes of initiation of treatment with glycerine as the dispersant and using the disc particulator.

Data collected on hand-held slides during this trial are shown in Table 6. These particulate data are collected for such a narrow span of the spectrum of particulate that was acting on the fog that they do not seem to contribute much to a better understanding of the results.

A quick look at the Particle Falling Rate Table in the Appendix will also point out the essentially total lack of credibility that can be given these slides because they would only collect particles in a highly specific size range. Even this can be true only if the data collector is careful to stand directly in the path of the falling particles.

E139. 09:51:30

E140. 09:51:52



E141. 09:52:10

E144. 09:53:47

E145. 09:54:05

E146. 09:54:24

Photo 144. 09:53:47

Photo 145. 09:54:05

Photo 146. 09:54:24

Photo E199. 10:34:03

Photo 199. 10:34:03

TABLE 5.

WIND MOVEMENT IN FEET FOR VARIOUS TIMES AND WIND SPEEDS

Hour: Min.	Wind Velocity, Knots 0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
9:48	0	0	0	0	0	0	0	0
9:50	101	203	304	405	506	608	709	810
9:52	203	405	608	810	1013	1215	1418	1620
9:54	304	608	911	1215	1519	1823	2127	2430
9:56	405	810	1215	1620	2025	2430	2836	3241
9:58	506	1013	1519	2025	2532	3038	3544	4051
10: 0	608	1215	1823	2430	3038	3646	4253	4861
10: 2	709	1418	2127	2836	3544	4253	4962	5671
10: 4	810	1620	2430	3241	4051	4861	5671	6481
10: 6	911	1823	2734	3646	4557	5468	6380	7291
10: 8	1013	2025	3038	4051	5063	6076	7089	8101
10:10	1114	2228	3342	4456	5570	6684	7798	8912
10:12	1215	2430	3646	4861	6076	7291	8507	9722
10:14	1316	2633	3949	5266	6582	7899	9215	10532
10:16	1418	2836	4253	5671	7089	8507	9924	11342
10:18	1519	3038	4557	6076	7595	9114	10633	12152

TABLE 6.

DATA COLLECTED ON HAND-HELD SLIDES DURING THE FOG DISPERSAL TRIAL 4 NOVEMBER 1971

			Description of Drops on the Slides					
Slide No.	Exposure Time Sec.	Began	Density Count Drops/100 mm^2	Median Size	Particle Size Ranges, microns* % < 30	% 30-60	% 60-100	% > 100
G-109	10	9:50	27	23.8	60	20	2.5	17.5
G-110	5	9:51	11	29.2	47	11.8	0	41.2
G-111	5	9:52	23	18.5	68.6	0	0	31.4
G-112	5	9:53	55	18.5	53.6	2.4	2.4	41.5

*The particle size distributions are given as percent of total particles counted. Each percentile represents that portion of the particles attributable to the size range specified.

ECOLOGICAL CONSIDERATIONS

Glycerine produced by Dow Chemical U. S. A. is food grade, non-toxic, has a very sweet taste, and has been observed (in field trials in Redwood Valley, California) to attract honey bees. Honey bees were noted flying onto the clothing and the hands of personnel wetted with glycerine. Since glycerine is infinitely soluble in water, it is readily rinsed away.

Diethylene glycol and tetraethylene glycol are not edible. However, they are relatively non-toxic. No harm is attendant with skin contact so long as the glycols are washed away with water within a reasonable length of time as is recommended for normal hygienic cleanliness.

Table 7 illustrates the calculated oxygen demand for these materials. These figures would be of use to determine the extent to which they could be permitted to enter flowing streams or other bodies of water.

TABLE 7.

OXYGEN DEMAND

Material	Molecular Weight	Oxygen as O_2 Required per Unit of Material	
		Moles O_2/Mole	Grams O_2/Gram
Glycerine	92.1	3.5	1.216
Diethylene Glycol	106.1	5.0	1.508
Tetraethylene Glycol	194.2	10.0	1.647

CONCLUSIONS

1. Laboratory trials and field trials have demonstrated that glycerine is an effective dissipation reagent for water droplets suspended in air (warm fog).

2. The particulation equipment developed (or modified) by Dow Chemical U. S. A. was successfully operated and shown to be suitable for small scale field experiments.

3. The use of a collimated beam incandescent light (spotlight) is excellent for qualitative evaluation of visibility improvement in night time fog dispersal trials.

4. Photography from an aircraft at moderate altitude (above 2,000 or up to 10,000 feet) is a good data collection and analysis technique for daytime fog dispersal trials.

5. Hot-air balloons used as equipment lifts for fog dispersal trials are generally good, but they have at least two drawbacks:

   a. The heat convection from the balloon causes fog to be dispelled above and beside the balloon.

   b. Instrument cables hanging straight down are difficult to position in the fog dispersal chemical particulate if any breeze prevails.

6. Redwood Valley experiments pointed out the need for a more objective means of evaluating the experimental results. Since visibility improvement is the critical parameter to be evaluated, a portable transmissometer which could be easily positioned in the field of influence would be a valuable aid.

APPENDIX

EXCERPTED DIARY OF DOW FOG DISPERSAL OPERATIONS IN CALIFORNIA

Monday, 18 October 1971: Arrived at Arcata, California last night. Observed hot-air balloon operations.

Equipment and 50 gallons of glycerine have arrived. Unpacked the equipment, inspected it and piped the feed tank and particulators. The particulator arbor was modified so that each centrifugal plate would feed an equal amount.

Tuesday, 19 October 1971: Today was rainy. No outdoor operations. Two tests were run to determine the effect of pressure on feed rates from the 22-gallon tank. The particulator was run. Wiring of the van was altered to provide power independent of commercial power. A second high pressure helium bottle was located to speed up operations. The particulator frame will be hung twenty feet below the balloon with 3/16" nylon line at each corner.

Wednesday, 20 October 1971: The morning was slightly foggy, but the wind was still blowing, so that tests could not be made; however, the hot-air balloon was launched. The particulator was carried aloft about thirty feet. There was not too much torque upon starting and there was no appreciable torque upon feeding glycerine to the particulator. There was some indication downwind there was some increased size of droplets. Tank was mounted in sling fashion from the end of the gondola. Fifteen gallons of glycerine were loaded into the tank and it was pressured to 30 pounds per square inch gauge.

Thursday, 21 October, 1971: Today was clear so there was no testing. Extended the extension cord 250 feet with two No. 10 single strand wires. A 500 watt, 110 volt search light was attached to the tether truck to view the light scatter of the fog. Attempted to find a method to keep our feed tank warm when it is not in use. The glycerine is quite viscous when cold.

The decision was made today to move operations to Redwood Valley because a better chance of fog is assumed than at the Arcata/Eureka Airport.

Friday, 22 October 1971: Spent the day preparing and moving to Redwood Valley. Found after visiting the site that there are about 20 acres of grassy meadow that are used as a Seventh-day Adventist summer camp.

Holes were bored in the particulator support plate so that air could come in from the top to direct the particles away from the plate. A pasteboard box, insulated with glass fiber battens, was made to fit over the feed tank to keep it warm when not in use. Two 100 watt light bulbs under the supply tank will furnish heat. All of our equipment was picked up at the airport ready for the trip to Redwood Valley. It appears reasonably definite at this point that the field test time will be extended into the first week of November.

Saturday, 23 October 1971: Moved to Redwood Valley during rain. The helium cylinder was fitted with quick connectors. The particulator was set on the ground to test at a supply tank pressure of 40 psi so that the F. A. A. Project Manager could see it operate.

Sunday, 24 October 1971: Up at 2:30 A.M. to get to Redwood Valley by 4:00 A.M. The FOGGY CLOUD project crew arrived by 3:00 A.M. but no fog developed, even as late as 8:30 A.M. The base of the fog was about 700 feet up and there was considerable wind. When the photo-observation plane flew over about 7:30 A.M., the fog tops extended up to about 2,200 feet, or about a 1,000-foot fog blanket. The hot-air balloon was inflated during this period then later deflated and stowed. Operations were shut down and rescheduled for about 9:30 P.M.

No fog was observed during the drive from the motel in Arcata to Redwood Valley. However, some radiation fog started forming about 10:00 P.M. The air was quite still with no visible movement of the anemometer, but upon shining the flashlight through the fog it was determined that the fog particles were moving quite extensively. The 500 watt searchlight was pointed upward at about a 30° angle in the fog to determine whether photographs could be made of this beam in the fog. One photograph showed the heat from the generator making schlieren in the fog. The other one showed the shaft of light extending all the way up to disappearance.

Monday, 25 October 1971: Shortly after 2:00 A.M. it was decided that the fog would not become workable and the wind had increased to about 12 knots blowing up the valley. We arrived back at the motel a little after 4:00 A.M. after leaving our feed tank and three cans of glycerine at the airport where they could warm next to a furnace.

The three drums and the tank were kept in the car on the previous day to keep the glycerine warm from the radiant heat of the sun, but at about 5:00 P.M. it was not warm. The 30-gallon tank and three drums were brought into the motel where they were put in bathtubs of hot water.

Moved to Redwood Valley using a pickup truck. Obtained supplies and rented a 17-foot camping trailer. Arrived about 8:30 P.M. and hooked up the power and water at the Redwood Valley site.

10:00 P.M.: Told to stand by in case fog developed which would be reported by the off-duty sheriff's man who guarded the equipment. Fog was reported a little before 10:00 o'clock but the fog was not close to the ground.

Tuesday, 26 October 1971: 5:00 A.M.: Found some light fog down to the ground with a heavy overcast. Tried to make some determinations of dense fog height with the help of the large 15" spotlight. Pointed the light at 45 degrees upward, then walked out below the beam to determine altitude to the base of the clouds. Schlieren were noted about 90 paces away from the light source. This was an effective way to locate the base of the thick fog because the schlieren were quite distinct even through the less dense fog present from the ground up.

The day was quite rainy and operations consisted of discussion of technical problems. The evening disclosed no fog up until 10:30 P.M.; however, there

was a slight amount of haze developing. The guard did not report any further fog throughout the night.

Wednesday, 27 October 1971: Since the glycerine was allowed to get cold because of lack of power at the site, the flow to the particulator was tested. It was found that the flow of glycerine was greatly hampered by the cold even though we used 75 pounds helium pressure. The glycerine was weighed in the feed tank by weighing one end of the feed tank. There was still no permanent power in the area by nightfall and the generators were not available to us.

Thursday, 28 October 1971: This was a clear day with a scheduled call-out for 10:00 P.M. Although the night was clear (the fog never developed) the project team remained on stand-by until 3:30 A.M.

Keeping the glycerine warm has been a problem. On the previous night when the alert was over, the 7KW generator was not plugged back into the heating system for the stored glycerine so it was cold and viscous again. The solution was kept warm for the next night by two 100 watt light bulbs placed beneath the covering insulated box. The 5-gallon cans were kept warm by electric heaters in the van.

Friday, 29 October, 1971: The day was quite clear. It was predicted there would not be fog during the night, but an alert was called for after 10:00 o'clock if fog developed. It did not develop. Commercial power on the site by 2:00 P.M.

Call came to confirm that we should continue on into the next week because Dow had signed the contract to do so. Asked to call F. A. A. in Washington to discuss the probability of not being able to obtain enough fog to complete our contractual agreement to feed three chemicals on three different tests.

Called the F. A. A. and informed them that there had not been any tests to date because of lack of fog. F. A. A. emphasized that we should make every effort to make tests during foggy periods. F. A. A. reconfirmed that we are to continue on into next week. Particle slides taken from the runs where cold glycerine was fed to the Dow particulator were read this morning and appeared normal in droplet size and distribution.

Saturday, 30 October 1971: The day remained cloudy and rainy, but it started to clear toward the end of the daylight hours. About dusk, the fog was setting in quite low in quite a few places in the valley. The prediction was that there would be no fog, so the FOGGY CLOUD project crew was released from stand-by. The fog conditions were checked several times during the evening and by about 11:00 o'clock the fog had settled in the valley for about an hour. The fog was not very dense and it was not thick vertically because the moon was still visible. We decided to try to make a test in this fog.

The particulator was hoisted between the Met van and the Charlie van which were about 12 feet apart. The feed tank containing 15 gallons of glycerine was located on the ground with the particulator up about 8 to 10 feet in the air. The balloon inflation blower was located about 20 feet back from the particulator, pointing upward toward it. The blower had a 15-inch diameter squirrel-cage impeller driven by a butane motor. Opening of the blower is about 16" x 19".

Test 1 consisted of feeding glycerine through the particulator at a tank pressure of 75 pounds. This was merely an observation run to see what would happen. The search light was located about 75 yards away from the particulator and pointed generally in the direction of the particulator, and between 30 and 60 degrees to the right of the particulator which would be up the canyon.

The elevation of the light was kept fairly low, probably not much over 20 to 30 feet above the ground in the vicinity of the particulator. The wind was about one to two knots and blowing up the canyon. During the time the particulator was in operation, there was an increase of heavy particles noted in the vicinity. As the beam was turned further away from the particulator, schlieren were noted in the beam of light. Some observers noted that there was rain. The schlieren were tracked and were quite easily seen. All observers (the guard, the owner of the test site, and three Dow men) were sure that the dispersant caused openings in the fog. The particulator was stopped, which eliminated the schlieren and left the fog uniform.

The purpose of the second run was to take photographs in the beam of the searchlight. The particulator was started again and the flow turned on at a tank pressure of 75 pounds per square inch for four minutes. A picture was taken on Polaroid 3000 film before the test. Two Polaroid 3000 film pictures were taken during the test. The first one did not show much change, but the second one showed visible change in the beam of the searchlight although particles could not easily be seen. The Polaroid 10,000 film was put in the camera and a picture taken after the operation was completed. It showed no schlieren. Observations during the second run were very similar to the first run. All observers noted the difference caused by the dispersion of the glycerine.

It was decided to make another run so that better pictures could be obtained with the Polaroid 10,000. The 35mm camera was obtained and some pictures were taken of the filling operation and of the equipment. There were also two Polaroid shots taken of the equipment prior to the operations. The fog reduced to such a low level that additional testing could not be performed.

The area was cleaned up and equipment put back in place. All operations were completed about 1:30 A.M.

Sunday, 31 October 1971: This was a bright clear day. Fog at night was slight.

Monday, 1 November 1971: Conference about procedure at 1:30 P.M. Project Director of FOGGY CLOUD IV had decided that most of the information they needed was completed, but the Dow information was lacking so this work was given first priority on all tests. It was agreed that some data could be collected from daytime tests. It was further agreed that tests would be made at 100 feet with their particle collection equipment at 30, 60, and 90 feet below the particulator. It was stated that particles were so small that they would drift quite a distance even in one knot wind, so night-time tests for fog dispersal were preferred, using the searchlight to determine fog dissipation.

An alert was called for 5:00 P.M. with the expectation that there would be some fog. There was, but it never became dense and after waiting until 12:00 P.M., the operation was shut down.

Tuesday, 2 November 1971: The clear air tests started right after 9:00 A.M. The first test consisted of a 30-second feed rate from an elevation of 100 feet to see where the fall-out was going to occur. Although there was not much wind, 2-3 knots, the cloud of particulate floated quite a distance away. The second run, like all these runs, was made from 100 feet. It was about a 5-minute burst during which the crew tried to move the cable containing the particle counters below the fall-out, but it was not possible because the wind blew the particles so far away. Men in the field some distance away were collecting some samples on slides. The glycerine was quite warm on the first two runs, but a third run was made where it was cooler, so consequently the feed rate was slower. Pictures were taken by both Dow and FOGGY CLOUD personnel. The fourth run consisted of feeding tetraethylene glycol and the fifth run consisted of feeding diethylene glycol. The day was quite clear except prior to 9:00 A.M. when some fog was in the valley. No troubles were noted on the runs except the last run where the power cord was caught around the particulator and prevented starting. There was a possible call-out for fog tests at 10:00 P.M.

Wednesday, 3 November 1971: There was not workable fog during the night or at 6:00 A.M. The day started out to be quite bright and clear. Clear air tests were made on the rotating screen impact atomizer. The first run was a low flow rate at lower speed and the second run was a higher flow rate, about a gallon and a half a minute.

Thursday, 4 November 1971: Up till 1:30 A.M. observing the slow development of fog. Fog had started about 8:00 P.M. the previous night, but it was never very dense nor was it very close to the ground--perhaps as much as 200 feet up. By 5:00 A.M. the fog was much the same, somewhat high above the ground, not too thick (the moon could be seen through it), and the weather balloon at 250 feet was visible without a light. The observation plane came over about 7:15 A.M. and indicated that the tops of the fog were about 1600 feet. The Assistant Project Director of FOGGY CLOUD IV called and asked what the situation was. Described the fog to him, telling him we would like to make a run. Tests were made and interviews were tape-recorded of the

observations. The particulator was carried up to about 500 feet and glycerine was dispersed at about one gallon per minute. There were definite indications that the tests were successful. However, the fog broke up completely after the test was completed.

Friday, 5 November 1971: The morning was clear and the day was spent packing in preparation for one more night of possible fog. By midnight the fog had not developed to any extent.

Satur 6 November 1971: Automatic release at 7:00 A.M. because the fog did n velop throughout the night. Got to the plane by 10:30 A.M. The particula nd the feed tank were shipped to Freeport by motor freight.

FIGURE 1. CALENDAR OF WEATHER AND EVENTS 17 OCT-6 NOV 71 (APPENDIX)

17 OCT CLEAR Arrive at Arcata.	18 OCT CLEAR Balloon flew. Carried their equipment up. Piping and checking our equipment.	19 OCT RAIN Feed rate tests of the equipment.	20 OCT A.M. FOG THEN WIND Our equipment goes up on the balloon and operates.	21 OCT CLEAR White wires added (250'), 500W spot-light put on truck. Decision to move to Red-wood Valley	22 OCT CLEAR Moving equipment to Redwood Valley Holes bored in Mg plate.	23 OCT RAIN Moving to Redwood Valley Ran Particula-tor for FAA on ground.
24 OCT FOG TOO HIGH BREEZY Warmed glycerine in bathtub. Drove out this P.M., took photos. SOME FOG THIS P.M.	25 OCT CLEAR Moved to Red-wood Valley today in a trailer. SOME FOG	26 OCT OVERCAST, RAINY, SOME FOG ON GROUND EARLY A.M. HAZE	27 OCT COOL, CLEAR Flow tests on cold glycerine (on ground). Alert this P.M. NO FOG	28 OCT CLEAR, COOL Little generator in use to warm glycerine. NO FOG	29 OCT CLEAR Power put in. Read slides on microscope. 10 P.M. Alert NO FOG	30 OCT CLOUDY, RAINY To town for supplies. Runs made between vans till 1:30 A.M. FOG
31 OCT CLEAR VERY LITTLE FOG	1 NOV CLEAR Dow runs get No. 1 priority now. 5:00-12:00 Alert. VERY LITTLE FOG	2 NOV CLEAR Clear Air Tests today. Five of them. Disc particu-lator. 10 P.M. Alert NO FOG	3 NOV CLEAR Clear Air Tests today Two of them. Micronair MODERATE FOG	4 NOV FOG IN A.M. FOG TEST TODAY NO FOG	5 NOV CLEAR Cleaning and packing to leave. NO FOG	6 NOV COOL, CLEAR Pack and go home.

TABLE 1. APPENDIX

STOKES LAW FALLING RATES FOR LIQUID DROPLETS (GLYCERINE DENSITY BASIS)

FALL RATE (CMS./SEC.) AND FALL TIME (MIN.:SEC) FROM 100FT. ALTITUDE

MIC.	CMS/SEC	MIN:SEC		MIC.	CMS/SEC	MIN:SEC		MIC.	CMS/SEC	MIN:SEC
10	1.5230	33:21	*	60	54.8269	0:56	*	110	184.2792	0:17
11	1.8428	27:34	*	61	56.6697	0:54	*	111	187.6449	0:16
12	2.1931	23:10	*	62	58.5429	0:52	*	112	191.0412	0:16
13	2.5738	19:44	*	63	60.4466	0:50	*	113	194.4678	0:16
14	2.9850	17: 1	*	64	62.3808	0:49	*	114	197.9250	0:15
15	3.4267	14:49	*	65	64.3454	0:47	*	115	201.4126	0:15
16	3.8988	13: 2	*	66	66.3405	0:46	*	116	204.9306	0:15
17	4.4014	11:33	*	67	68.3661	0:45	*	117	208.4791	0:15
18	4.9344	10:18	*	68	70.4221	0:43	*	118	212.0581	0:14
19	5.4979	9:14	*	69	72.5085	0:42	*	119	215.6676	0:14
20	6.0919	8:20	*	70	74.6255	0:41	*	120	219.3074	0:14
21	6.7163	7:34	*	71	76.7728	0:40	*	121	222.9778	0:14
22	7.3712	6:54	*	72	78.9507	0:39	*	122	226.6786	0:13
23	8.0565	6:18	*	73	81.1590	0:38	*	123	230.4099	0:13
24	8.7723	5:47	*	74	83.3977	0:37	*	124	234.1716	0:13
25	9.5186	5:20	*	75	85.6670	0:36	*	125	237.9638	0:13
26	10.2953	4:56	*	76	87.9667	0:35	*	126	241.7865	0:13
27	11.1024	4:35	*	77	90.2968	0:34	*	127	245.6396	0:12
28	11.9401	4:15	*	78	92.6574	0:33	*	128	249.5231	0:12
29	12.8082	3:58	*	79	95.0485	0:32	*	129	253.4372	0:12
30	13.7067	3:42	*	80	97.4700	0:31	*	130	257.3817	0:12
31	14.6357	3:28	*	81	99.9220	0:31	*	131	261.3566	0:12
32	15.5952	3:15	*	82	102.4044	0:30	*	132	265.3620	0:11
33	16.5851	3: 4	*	83	104.9173	0:29	*	133	269.3979	0:11
34	17.6055	2:53	*	84	107.4606	0:28	*	134	273.4642	0:11
35	18.6564	2:43	*	85	110.0345	0:28	*	135	277.5610	0:11
36	19.7377	2:34	*	86	112.6387	0:27	*	136	281.6882	0:11
37	20.8494	2:26	*	87	115.2735	0:26	*	137	285.8459	0:11
38	21.9917	2:19	*	88	117.9387	0:26	*	138	290.0341	0:11
39	23.1643	2:12	*	89	120.6343	0:25	*	139	294.2527	0:10
40	24.3675	2: 5	*	90	123.3604	0:25	*	140	298.5018	0:10
41	25.6011	1:59	*	91	126.1170	0:24	*	141	302.7813	0:10
42	26.8652	1:53	*	92	128.9040	0:24	*	142	307.0913	0:10
43	28.1597	1:48	*	93	131.7215	0:23	*	143	311.4318	0:10
44	29.4847	1:43	*	94	134.5695	0:23	*	144	315.8027	0:10
45	30.8401	1:39	*	95	137.4479	0:22	*	145	320.2041	0:10
46	32.2260	1:35	*	96	140.3568	0:22	*	146	324.6359	0: 9
47	33.6424	1:31	*	97	143.2961	0:21	*	147	329.0982	0: 9
48	35.0892	1:27	*	98	146.2659	0:21	*	148	333.5910	0: 9
49	36.5665	1:23	*	99	149.2661	0:20	*	149	338.1142	0: 9
50	38.0742	1:20	*	100	152.2968	0:20	*	150	342.6679	0: 9
51	39.6124	1:17	*	101	155.3580	0:20	*	151	347.2520	0: 9
52	41.1811	1:14	*	102	158.4496	0:19	*	152	351.8666	0: 9
53	42.7802	1:11	*	103	161.5717	0:19	*	153	356.5117	0: 9
54	44.4098	1: 9	*	104	164.7243	0:19	*	154	361.1872	0: 8
55	46.0698	1: 6	*	105	167.9073	0:18	*	155	365.8932	0: 8
56	47.7603	1: 4	*	106	171.1207	0:18	*	156	370.6296	0: 8
57	49.4812	1: 2	*	107	174.3647	0:17	*	157	375.3965	0: 8
58	51.2327	0:59	*	108	177.6390	0:17	*	158	380.1938	0: 8
59	53.0145	0:57	*	109	180.9439	0:17	*	159	385.0216	0: 8
60	54.8269	0:56	*	110	184.2792	0:17	*	160	389.8799	0: 8

GLOSSARY OF TERMS

1. Ambient: Encompassing on all sides; the prevailing natural condition of material (e.g. pressure or temperature of the surrounding atmosphere).

2. Atomizer: Used in this report to indicate a device for generating small droplets of liquid.

3. Centipoise: Measurement of fluid viscosity. One hundredth of a poise. A poise is a viscosity of one gram per centimeter per second.

4. Enthalpy: The sum of the internal and external energies of a fluid system; thermodynamic potential or heat content at constant pressure.

5. GPM: Gallons per minute. A rate of flow.

Hydraulic Atomizer: A device used to generate droplets of liquid. liquid is spun with the axis of rotation parallel to the direction of [illegible]. It then enters a cavity and the spinning liquid is then forced to flow out thru an orifice.

7. Lb./In.^{2} Gage: Pounds per square inch gauge, See also Psig.

8. Micron: Unit of length. One millionth of a meter.

9. Ml/min.: Milliliters per minute flow rate.

10. Pin-jet impingement: A method used to generate very small droplets of liquid. Liquid is forced thru a small orifice and is caused to strike the end of a small metal pin thereby generating a spray of droplets of the liquid.

11. Psig: Pounds of pressure per square inch gauge. "Gauge" pressure measures from ambient atmospheric pressure as datum zero.

12. Schlieren (German): Regions of varying refraction in a medium (e.g., heat waves in air). Also used in this report to indicate varying reflectance or light scatter effects in fog.

13. Spiral Nozzle: A device used to generate very small droplets of liquid. A tapered thick wall hollow tube is cut with a continuous slot which spirals down the tube. The shape of the nozzle is somewhat like a hollow center wood bit. Liquid flowing into the spiral sprays out thru the slot.

14. Tyndall Effect: The luminosity of the path of a beam of light. It indicates the presence of suspended particles.

15. Whirl Nozzle: A device used to generate small droplets of liquid. The body of this nozzle is a hollow cylinder which contracts to a venturi-like orifice. Just upstream of the orifice, a shaped, non-moving insert causes the liquid at the wall to rotate with its axis parallel to the cylinder. Liquid at the center of the cylinder flows straight thru toward the orifice. The rapid rotation in the orifice causes a spray of small droplets.